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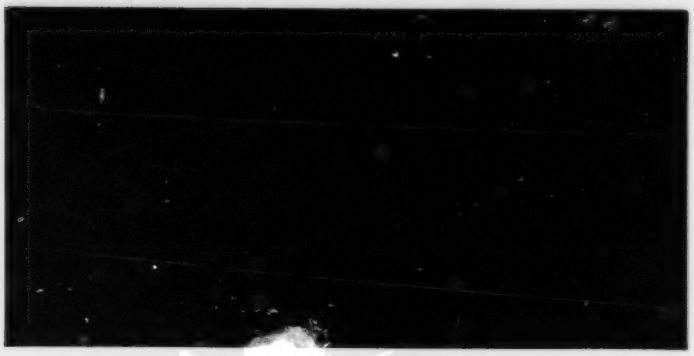

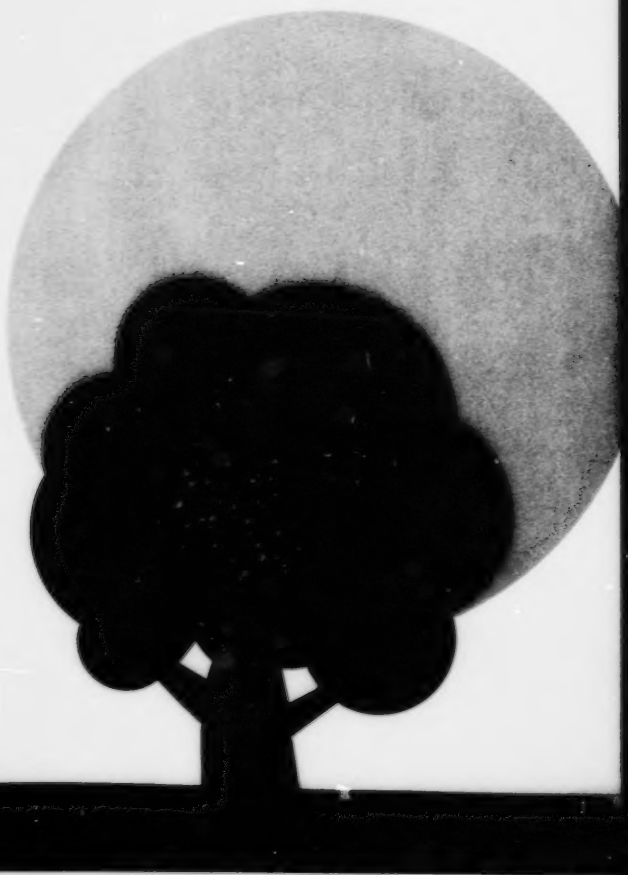

Canada

THE EFFECT OF FRAME DESIGN ON WINDOW HEAT LOSS

- PHASE I

FINAL REPORT

RENEWABLE ENERGY BRANCH

PREPARED FOR:

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PREPARED BY:

Enermodal Engineering Limited
368 Phillip Street, Unit 2
Waterloo, Ontario
N2L 5J1

SCIENTIFIC AUTHORITY:

Mr. Timothy Mayo
Passive Solar Technology Coordinator

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Solar Energy Division
Renewable Energy Branch
Energy, Mines and Resources Canada
580 Booth Street
Ottawa, Ontario
K1A 0E4
(613) 996-7516

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PREFACE

The purpose of this report is to examine the potential for improved window performance (U-value) by improving the frame and spacer design. The report examines both commercially available and new concepts in window framing. For confidentiality reasons, some of the new concepts are not illustrated or described in detail.

This report is intended for window manufacturers, window specifiers and government officials (as a supporting document for the super-window development program). The reader is cautioned that the results presented are for the window geometries studied and may not be applicable for other frame/spacer designs.

Phase II of this project will focus on making the computer analysis program "user-friendly" and available to the window design community.

PRÉFACE

L'objet du présent rapport est d'étudier la possibilité d'améliorer le rendement des fenêtres (coefficient U) par une meilleure conception des châssis et des baguettes d'espacement. On examine les châssis de conception nouvelle ainsi que les châssis déjà sur le marché. Pour des raisons de confidentialité, certains des châssis de conception nouvelle ne sont pas illustrés ou décrits en détails.

Le rapport est destiné aux fabricants de fenêtres, à ceux qui en définissent les caractéristiques et aux fonctionnaires gouvernementaux (comme document d'appui au programme de mise au point de la super-fenêtre). Il est à noter que les résultats présentés se rapportent aux géométries étudiées et peuvent ne pas s'appliquer à d'autres modèles de châssis ou de baguettes d'espacement.

L'étape II du projet consiste à simplifier l'utilisation du programme d'analyse informatique et à le mettre à la disposition des concepteurs de fenêtres.

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EXECUTIVE SUMMARY

This report examines the potential improvement in window thermal resistance through the use of advanced, commercially available window frames and spacers.

The heat transfer analysis was carried out using the finite difference computer program **FRAME**, based on the Swedish program **BJ2ST** developed by the Lund Institute of Technology [1]. Temperature and heat flow distributions have been determined for fixed picture windows of various frame and spacer materials. Thermal performance is presented in terms of total window U-values and ASHRAE Adjustment Factors (the ratio of total window U-value to that of the glazing alone).

Incorporating a fiberglass, butyl rubber, or stainless steel spacer into a double-glazed picture window design can result in a six percent reduction in the overall window U-value, for standard double-glazed windows, or a ten percent reduction for low-emissivity double-glazed windows.

The thermal performance of the separate components of a window assembly cannot be considered independent of one another, due to a conductive interaction between frame, spacer, and glazing.

Depending on the framing material, the U-value of a double-glazed picture window may vary by up to forty-three percent. A polyurethane foam filled PVC frame resulted in the lowest overall window U-value.

It is recommended that the **FRAME** computer program be made available to window frame manufacturers, thus providing a necessary tool to evaluate and optimize designs.

SOMMAIRE

Le présent rapport rend compte de la possibilité d'améliorer la résistance thermique des fenêtres, en utilisant des châssis et des baguettes d'espacement de qualité supérieure offerts sur le marché.

On a analysé la transmission de chaleur à l'aide du programme informatique **FRAME** à éléments finis, basé sur le programme suédois BJ2ST mis au point par le Lund Institute of Technology [1]. Les distributions de la température et de la transmission de chaleur ont été calculées pour des fenêtres panoramiques fixes dont les châssis et les baguettes d'espacement sont faits de divers matériaux. Les rendements thermiques sont présentés en terme de coefficients U des fenêtres entières et de facteurs d'adjustement ASHRAE (rapport du coefficient U de la fenêtre entière à celui du vitrage seul).

L'inclusion d'une baguette d'espacement de fibre de verre, de caoutchouc butyle ou d'acier inoxydable dans la construction d'une fenêtre panoramique à double vitrage peut entraîner une réduction de six pour cent du coefficient U de la fenêtre entière dans le cas de vitrages ordinaires ou de dix pour cent dans le cas de vitrages à faible coefficient d'émission.

Les rendements thermiques des diverses composantes d'une fenêtre ne peuvent être considérés comme indépendants les uns des autres, en raison de la conductibilité des diverses composantes (châssis, baguette d'espacement et vitrage).

Le coefficient U d'une fenêtre panoramique à double vitrage peut varier de près de 43 pour cent selon le matériau utilisé pour le châssis. Le coefficient U le plus bas pour la fenêtre entière a été obtenu en utilisant un châssis de chlorure de polyvinyle rempli de mousse de polyurétane.

Nous recommandons que le programme informatique **FRAME** soit mis à la disposition des fabricants de châssis de fenêtre pour leur permettre d'évaluer et d'améliorer les diverses conceptions.

1. INTRODUCTION

Heat transfer through windows consists of an interaction between conduction, convection, and radiation between the panes and within the frame. The flow of heat through the centre of the window is dominated by radiation and can be calculated quite accurately using basic heat transfer theory. When examining an entire window, however, the transfer process becomes increasingly complex, especially at the glazing/frame interface where two and three dimensional heat flow results. In addition, multi-component frames and complicated construction make conventional techniques for determining window U-values inaccurate.

As a result of this complicated interaction, the window frame and spacer have been an often overlooked component in the design of high resistance "super" windows. The frame, being the most expensive part of a window, in many cases represents twenty to thirty percent of the rough window opening and has a thermal resistance equivalent to double glazing. Because the frame does not transmit solar radiation, it results in a significant net building heat loss.

This report examines the potential improvement in window thermal resistance through the use of advanced commercially available window frames and spacers. A finite-difference computer program is used to perform the analysis.

2. IMPROVED WINDOW FRAME FEATURES

Recent advancements in glazing technology, such as inert gas fill and low-emissivity coatings, have produced commercially available glazing systems superior to conventional windows. With advanced glazing systems available, efforts have been made to improve window frame resistance.

Improvements to the window frame can be divided into two groups: spacers and frames. In conventional single-sealed glazing units, an aluminum channel, back-filled with sealant, is used to separate the glazings. Use of aluminum results in high heat transfer at the glazing edge, producing condensation on the inner glazing surface during cold weather. Use of an insulated spacer increases the minimum glazing temperature, thereby eliminating condensation during cold weather. Analytical studies carried out at the Lund Institute of Technology have shown that the use of an insulated spacer results in a five percent reduction in overall window heat loss (approximately thirty percent reduction through the frame alone). Because the glazings remain at a more uniform temperature, the problem of cold weather thermal stress is alleviated.

Materials of low thermal conductivity, such as fiberglass and polyvinyl choride (PVC), are now being used as window frame materials. These materials have the advantage of possible reduction in window frame area. Reducing the area of the frame decreases conductive losses while increasing solar gains. Studies performed by Enermodal Engineering Limited [8] have shown that, for a typical house with the majority of windows on the south side, possible energy savings of four to five gigajoules per year can be achieved by improving frame design.

3. THE ANALYSIS TECHNIQUE

3.1 The Program

The heat transfer analysis was carried out using a two dimensional, steady-state, finite-difference computer program. This computer program is based on the Swedish computer program **BJ2ST** developed by the Lund Institute of Technology [1], with the addition of improved input, graphical output, and internal heat generation capabilities. The program has been compared to experimental results and was reported to be accurate within ten percent [1].

The program has a maximum grid size of 65 x 65 cells of variable dimensions. A value for thermal conductivity can be assigned to each cell. The thermal conductivity of interior air spaces is a combined convective-radiative value and is assumed constant for the calculations (see Section 3.2). Boundary conditions can be specified as either constant temperature or constant heat flux.

Calculations are carried out by expressing the heat conduction equations as finite differences and solving them by successive substitutions. The convergence technique employed is the method of successive overrelaxation (SOR). When the heat flows in and out of the window assembly are found to agree within 0.1 percent, the calculations are considered to have converged.

The program outputs the average cross-section temperature distribution and heat flow distributions in both the x and y directions. The total heat flow and temperature change across each boundary is also presented. In addition to this numerical output, graphical output is available in the form of a temperature isotherm plot. A typical program output is included in Appendix A.

The total window heat loss is determined using an area-weighted average applied to the heat flow through each portion of the window. That is, the heat flow through the frame, sill, edge glazing (considered to be 100 mm of the perimeter glazing), and the centre glazing are weighted corresponding to their respective total areas. The total window U-value can then be determined from this average heat flow and the known temperature difference across the window assembly. A sample calculation for the determination of the total window U-value is included in Appendix B.

3.2 Air Space Heat Transfer

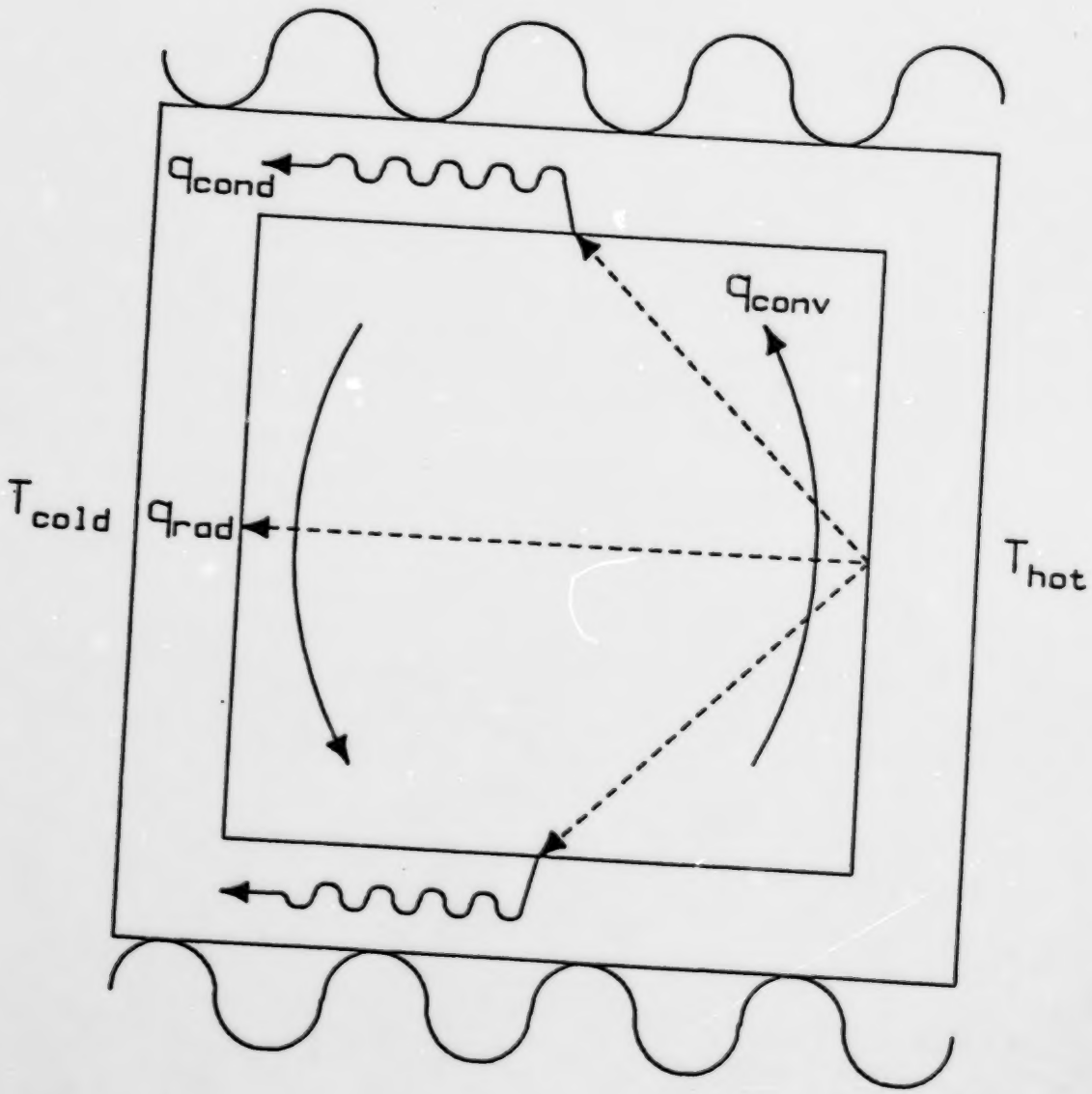
Heat transfer within enclosures has three components: conduction, convection, and radiation. Conductive heat transfer is easily modelled; however, when convection and radiation transfer across an air space are included in a finite-difference calculation, the program becomes extremely cumbersome. The temperature of an individual cell is no longer a function of only its neighbouring cells, but of all the cells in which there is a conductive, convective, or radiative coupling.

For enclosed air spaces, calculation of radiative heat transfer is extremely complicated. Consider the portion of the window cross-section shown in Figure 1. This cross-section may represent a window spacer or a channel in a PVC frame. Heat will be radiated from the hot to the cold side. Some of the radiation will be transmitted directly across the enclosure, while some will strike the side walls and be conducted to the cold side. Thus, the net radiative heat transfer is a function of the material used, the shape of the space, and, of course, the mean temperature.

A common technique used to simplify this problem is to ignore radiation and convection and increase the conductivity of the air space such that the total heat transfer across the enclosure remains the same [1]. The equation for the effective conductivity can then be written as:

$$k_{eff} = k_{air} \cdot Nu + \frac{(h_r \cdot x)}{[1/\overline{\varepsilon_H} + 1/\overline{\varepsilon_C} - 1)}$$

FIGURE 1. MODES OF HEAT TRANSFER WITHIN ENCLOSURES



where k_{air} is the conductivity of still air (= 0.0263 W/m/K)

Nu is the Nusselt number = hx/k

x is the distance across the enclosure (in the direction of heat flow)

h_r is the black body radiation heat transfer coefficient (W/m2/K) (see Table 1)

$\overline{\varepsilon_H}$, $\overline{\varepsilon_C}$ are the average (long-wave) emissivities of the hot and cold surfaces of the enclosure, respectively (see Figure 1).

A specialized computer program was developed to determine the radiation heat transfer coefficient. The temperature and heat flow distributions across a typical enclosure were obtained for two cases: with and without radiation. Analysis was carried out for two types of materials and for a range of aspect ratios, assuming a mean temperature of zero degrees Celsius across the cavity. Materials used in window systems can be divided into two groups of similar thermal properties: low-conductivity/high-emissivity (e.g. PVC, fiberglass, wood) and high-conductivity/low-emissivity (e.g. aluminum, steel). For metallic materials, the radiative heat transfer is essentially negligible because of the low emissivity and the small temperature difference (resulting from its high thermal conductivity). For non-metallic materials, the radiative heat transfer coefficient is presented in Table 1.

The **VISION** computer program [2] can be employed to determine the average Nusselt number between two parallel plates. For a 12.5 mm air space and a 40 degree Celcius temperature difference across the window, the program predicts a Nusselt number of approximately 1.1. Values for the Nusselt number for the window frame cavities were calculated using correlations recommended in reference [3]. The Nusselt number was found to vary between 1.1 and 10.1, depending on geometry and temperature difference.

Table 1. Black Body Radiation Heat Transfer Coefficient for Typical Window Air Spaces *

Aspect Ratio (Height/Width[1])	h_r (W/m²/K)
0	0
1/3	2.57
1	3.53
∞	4.62

* Coefficients were determined for a mean temperature of 0°C.

1 In the direction of heat flow (i.e., equal to x).

3.3 Program Validation

The **BJ2ST** program was chosen for the study, because it had undergone extensive validation. Comparing program results to experimental results, the Lund Institute found the program was accurate within 10% [1] in predicting absolute U-value. The program would have a significantly better accuracy in comparing one design to another.

Validating the computer program using Canadian data has proven difficult. Most window testing has been done for window manufacturers and is kept confidential. One exception is the testing by Ontario Research Foundation [10] of three window systems containing aluminum, fibreglass and butyl rubber spacers. Their results show that the fibreglass and butyl rubber spacer window had almost identical performance and, at 90% glass area, had a U-value 3.5% better than the aluminum spacer window. The **FRAME** computer program matches very closely at 3.1% improvement (see Table 3).

Further program validation will be carried out in the second phase of the project.

4. THE STUDY

Ideally, any study attempting to determine window thermal performance should be carried out by testing a large number of window assemblies. This approach, however, may not be accurate enough to distinguish minor changes in frame design. An alternative to this expensive and time-consuming method is to use a finite-difference computer program to solve for the window temperature and heat flow distributions. While computer solutions may not produce exact results, they provide an excellent method for determining the effect of minor design changes and for comparing alternative designs.

This study investigates the effect of four improved spacers on window heat loss as compared to a typical single-seal aluminum spacer. The improved spacers consist of a pultruded fiberglass spacer, an extruded butyl rubber spacer, a very thin metallic spacer, an insulated spacer, and a "perfect" spacer. The fiberglass spacer is a 9.5 x 12.5 mm channel with 1.78 mm thick walls. The assembly is back-filled with a polysulphide sealant, thus providing a single seal. The butyl rubber spacer contains a corrugated strip of 0.1 x 11 mm aluminum to improve rigidity. During the assembly process the butyl rubber is compressed to seal the glazing, thereby eliminating the need for back-filling with sealant. The metallic spacer is simply a thin strip of stainless steel, 0.15 mm in thickness. The insulated spacer is composed of an insulating material with a thin metal foil backing and a polyurethane sealant.

The windows are modelled with both ordinary plate glass (ε = 0.84) and low-emissivity (ε = 0.09) glazings, as well as some high-performance glazings which incorporate a thin low-ε coated polyester film (PET) between the two lites of glass. A triple-glazed window is also included for completeness of scope. In addition to the four improved spacers, the effect of using a larger bite (the depth of glazing penetration into the frame) on window heat loss is examined. For this portion of the study, only two spacers, aluminum and fiberglass, are examined.

Several companies are conducting research into spacers that have a high thermal resistance. The high resistance can be accomplished by either using low conductivity spacers or very thin spacers. To determine the maximum potential of these products, the case of the "perfect" or non-existent spacer is included.

Six types of residential fixed window frames are investigated. These are: aluminum, thermally-broken aluminum, wood, fiberglass, PVC, and PVC with polyurethane foam filled cavities. Three profiles, shown in Figures 2, 3 and 4, were used to model the window assemblies. Because it is not possible to analyse every design of window frame produced from these materials, one design for each case was chosen as representative of a major manufacturer's product. The reader is cautioned, however, that the results presented pertain only to the designs shown in Figures 2, 3 and 4. Further, as the thermal conductivity represents an extremely important input to the program, frames produced using materials with thermal conductivity values varying from those presented in Table 2 will, undoubtedly, exhibit different heat loss characteristics.

4.1 The Input Data

The input to the **FRAME** program consists of four steps:

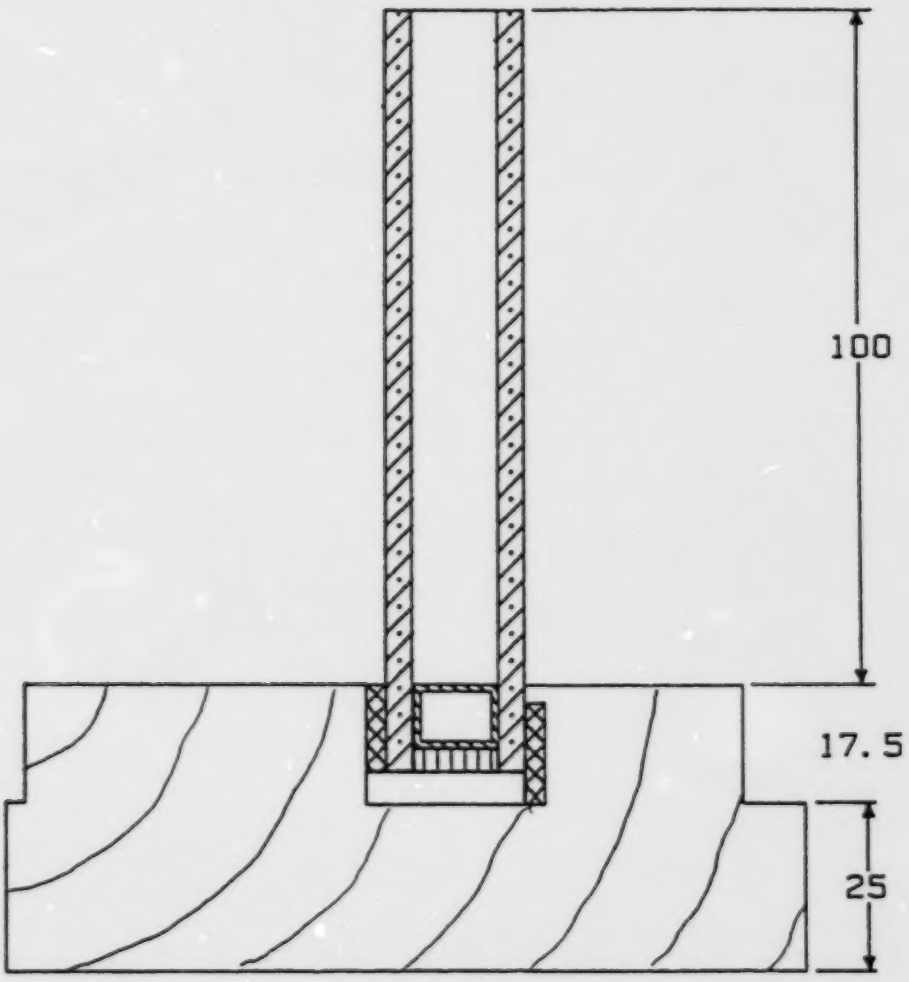
i) assigning the grid size and cell dimensions,
ii) describing the window assembly geometry by describing areas or subregions of similar properties,
iii) assigning thermal conductivity values to each subregion, and
iv) describing the boundary conditions.

For all the window frames analysed, the grid was produced such that there were no large increments between subregions. Figure 5 displays a sample input diagram showing the refinement of the grid and the breakdown

Table 2. Thermal Conductivity of Window Materials

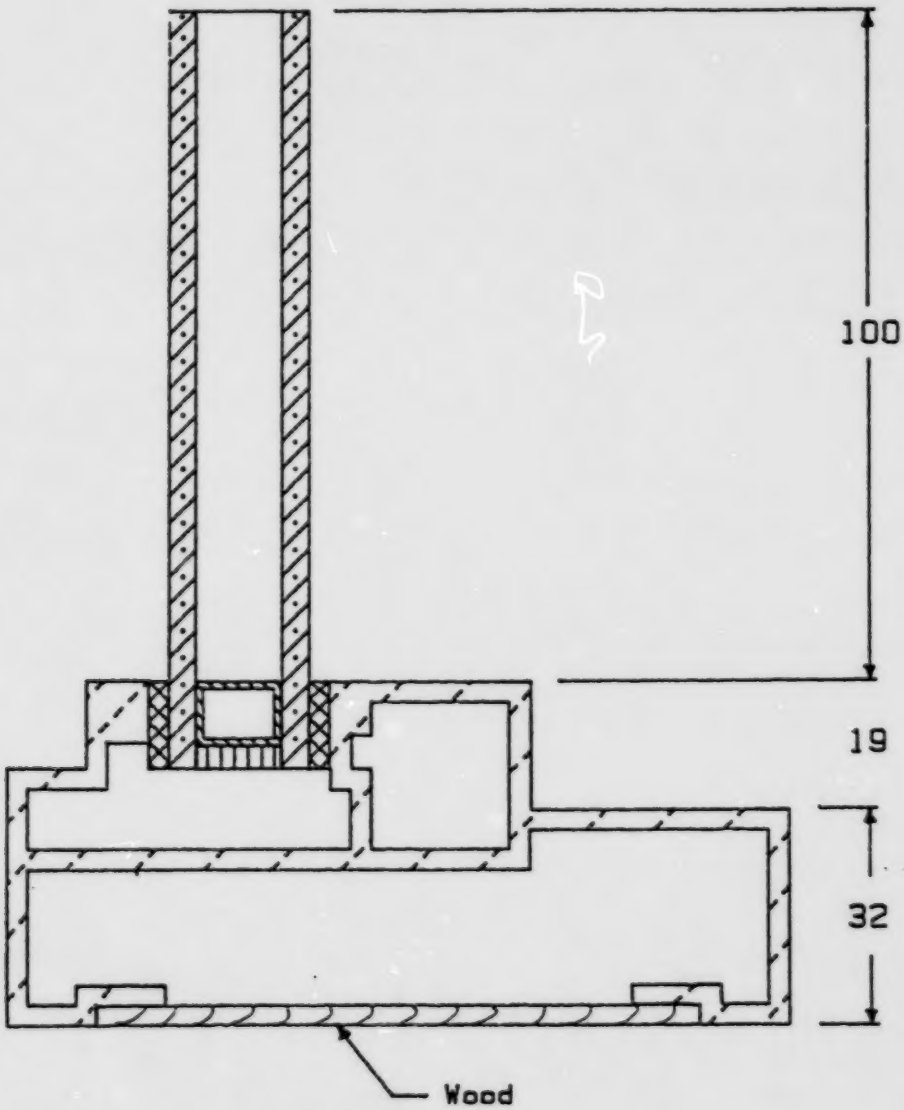
Symbol	Material	k (W/m/K)	Reference
	Aluminum	210.00	4
	Wood	0.14	4
	Glass	1.00	5
	Butyl Rubber	0.13	5
	Polyvinyl Chloride (PVC)	0.17	6
	Poltruded Fiberglass	0.30	7
	Polysulphide	0.30	5
	Still Air	0.0263	5
N/A	Polyurethane	0.03	9
N/A	Stainless Steel	14.3	9

FIGURE 2. WOOD FRAME



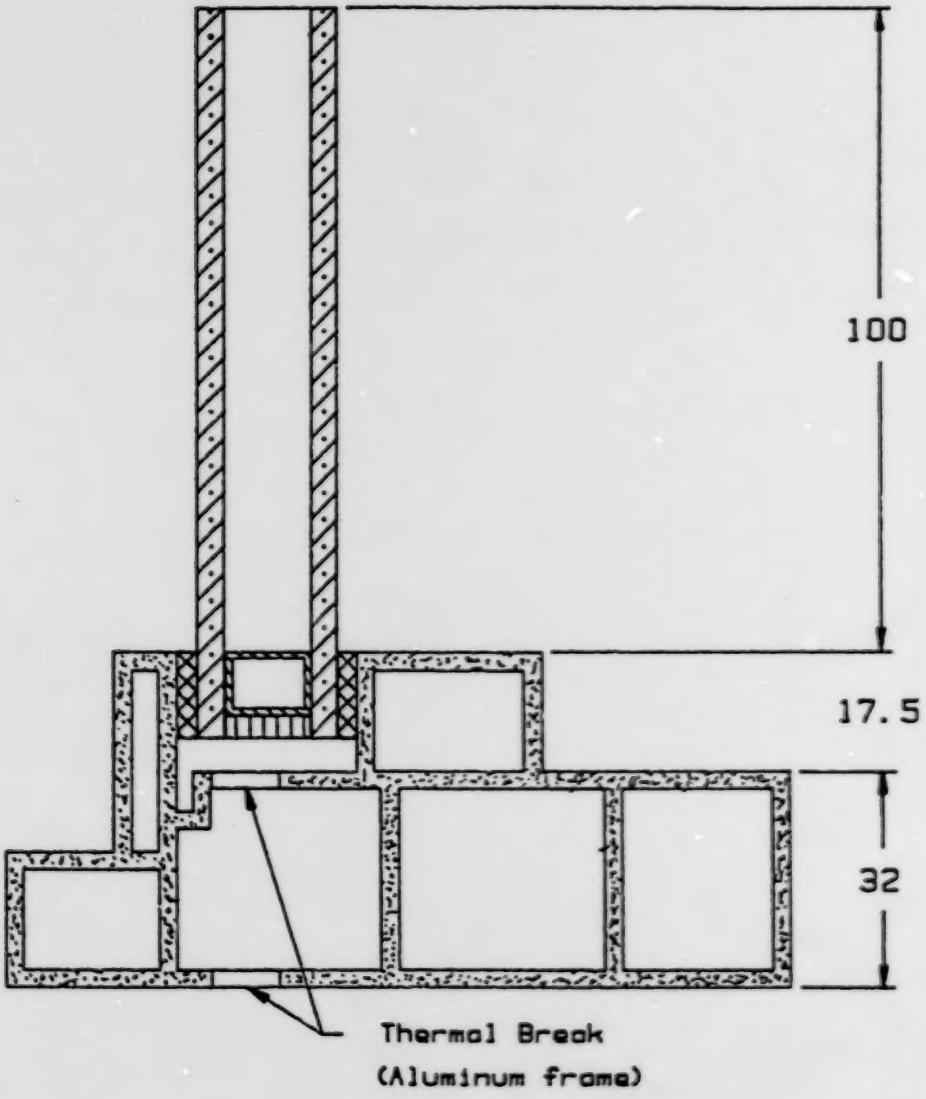
Dimensions shown in millimeters.

FIGURE 3. FIBERGLASS FRAME



Dimensions shown in millimeters.

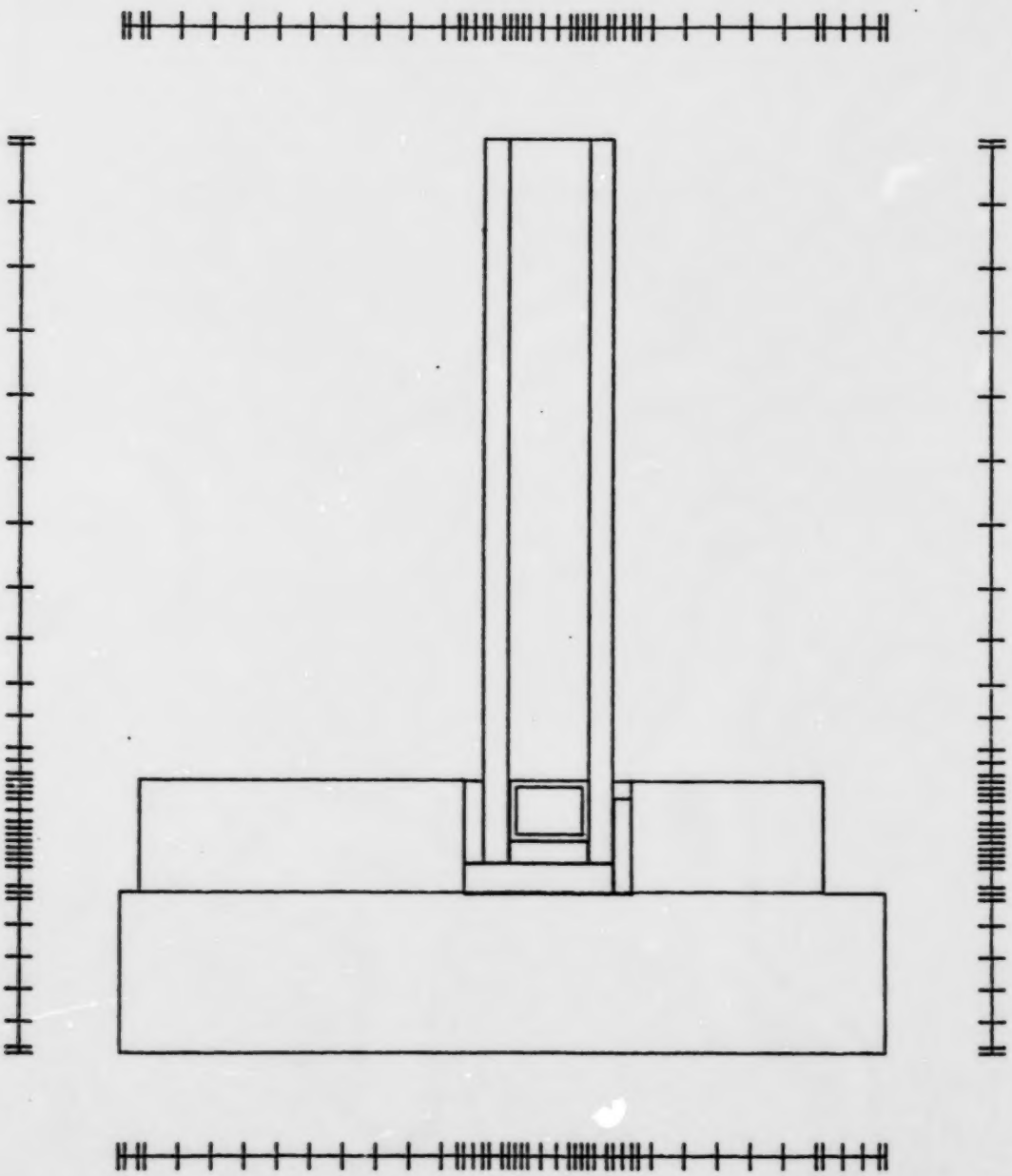
FIGURE 4. PVC FRAME



Note: This profile was also used for the aluminum frames.

Dimensions shown in millimeters.

FIGURE 5. PROGRAM INPUT DIAGRAM FOR A WOOD FRAME



Note: The grid is refined at the boundaries between subregions and in the location of the aluminum spacer.

of the window into subregions. The grid is refined in the locations of greatest expected heat flow variation. For this particular example, the area near the aluminum spacer is expected to exhibit large changes in heat flow. Notice that only a portion of the glazing system is analysed: the centre glazing heat flow is assumed to be one-dimensional and can, therefore, be determined quite easily without using a finite-difference model.

Table 2 presents the thermal conductivity values used in the program. It should be noted, however, that actual material thermal conductivity values may vary depending upon the manufacturer.

The description of the boundary conditions includes the input of temperature and resistance. For all cases studied, the indoor and outdoor boundary temperatures were set to the ASHRAE winter design conditions of 21 and -18 degrees Celsius, respectively.

Heat flow from the window frame into the insulated wall was assumed negligible (i.e., a very large resistance was fixed along this boundary). As the centre glazing heat flow is assumed to be one-dimensional, the upper glazing boundary is also considered to be well insulated. The temperature of the highly insulated boundaries does not influence the window heat flow, for obvious reasons.

For the exterior window surface, heat transfer is dominated by forced convection due to wind conditions. For this study, the exterior air film resistance was assumed constant. The analysis was performed using ASHRAE winter design conditions [9]. The **VISION** computer program calculated an exterior boundary resistance of 0.035 m^2K/W.

For the interior air film, the heat transfer consists of approximately two-thirds radiation and one-third convection. Thus, errors in estimating the local convective coefficient or the local air temperature should have only a minor effect on the total heat transfer. The temperature

the inner glazing "sees" for radiation purposes should be very close to the room air temperature. Thus, a constant interior air film resistance should produce reasonable results. The **VISION** program calculated a value of 0.132 m^2K/W for the interior boundary resistance.

5. DISCUSSION OF RESULTS

The actual U-values presented in this section will vary throughout the year, depending on the indoor/outdoor temperature differential and on the wind conditions. The percentage improvement over aluminum should, however, remain constant. Once again, the reader is cautioned that the results presented pertain only to the window profiles shown in Figures 2, 3 and 4.

5.1 Spacer Design

Table 3 displays the total window U-value (glazing and frame) for the five spacers examined. Also included in Table 3 and Figure 6 (and subsequent tables) are values for the Adjustment Factor, or the ratio of total window U-value to glazing U-value. These values are used by ASHRAE [9] in determining heat loss for a given type of glazing, according to window frame (and spacer) type. The results are presented for three percentage glazing values and correspond to the heat flow through a wood frame with a standard double-glazing.

From the data presented in Table 3, it can be seen that the total window U-value can be decreased by 3 to 6 percent by using a fiberglass, butyl rubber, or stainless steel spacer. These results are consistent with those presented by Jonsson [1]. While the stainless steel spacer has the highest thermal conductivity, it results in the highest resistance to heat flow: this is a direct result of its very thin profile. The ideal or "perfect" spacer demonstrates a possible reduction in total window U-value of up to 8 percent, or approximately 1.4 percent improvement over stainless steel.

Figure 7 shows a window isotherm plot, in two degree Celcius increments, for the aluminum spacer window (in a wood frame). The impact of the aluminum spacer on the window heat flow is quite dramatic. Because of its high thermal conductivity, the aluminum spacer is essentially isothermal. The effect of replacing the aluminum spacer with a fiberglass spacer can be seen in Figure 8. While the overall window heat loss is reduced, the average inner glazing temperature increases, thus reducing the tendency for condensation to form.

Table 3. Effect of Spacer Design on Standard Window U-Value *

Spacer Material	Glazing Area (%)	Overall Window Performance U-Value ($W/m^2/K$)	Adjustment Factor	Improvement (%)
Aluminum	80	2.87	1.01	base
Aluminum Double-Seal	80	2.81	.99	2.1
Fiberglass	80	2.70	.95	5.9
Butyl Rubber	80	2.69	.95	6.3
Stainless Steel	80	2.68	.94	6.6
Insulated	80	2.68	.94	6.6
No Spacer	80	2.64	.93	8.0
Aluminum	85	2.87	1.01	base
Aluminum Double-Seal	85	2.82	.99	1.7
Fiberglass	85	2.74	.96	4.5
Butyl Rubber	85	2.74	.96	4.5
Stainless Steel	85	2.73	.96	4.9
Insulated	85	2.72	.96	5.2
No Spacer	85	2.69	.95	6.3
Aluminum	90	2.87	1.01	base
Aluminum Double-Seal	90	2.84	1.00	1.0
Fiberglass	90	2.78	.98	3.1
Butyl Rubber	90	2.78	.98	3.1
Stainless Steel	90	2.77	.98	3.5
Insulated	90	2.77	.98	3.5
No Spacer	90	2.74	.96	4.5
No Frame/No Spacer	100	2.84	1.00	-

* U-Value calculations presented for a wood frame and standard double-glazing.

Figure 6

EFFECT OF SPACER MATERIAL ON ADJUSTMENT FACTOR

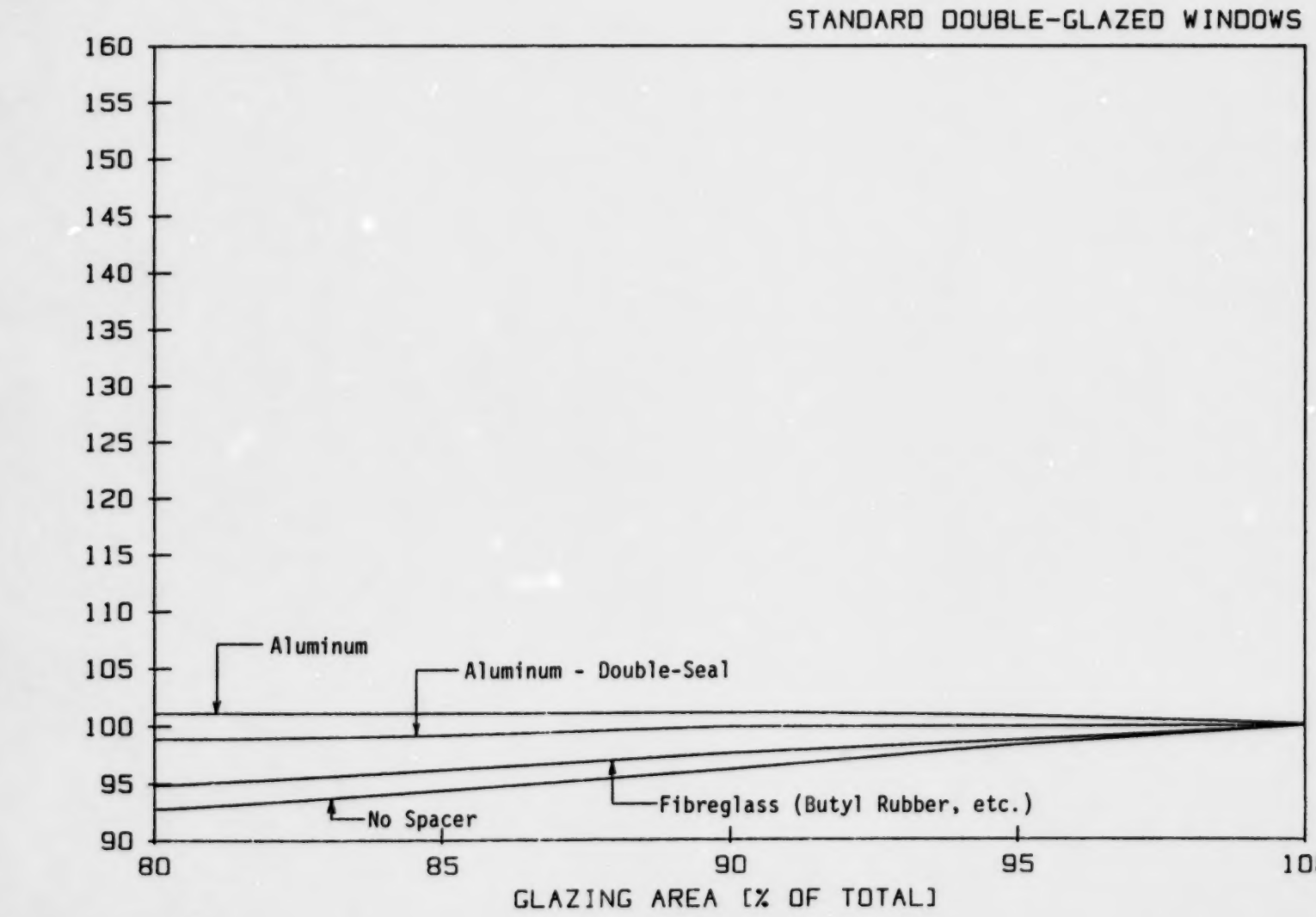
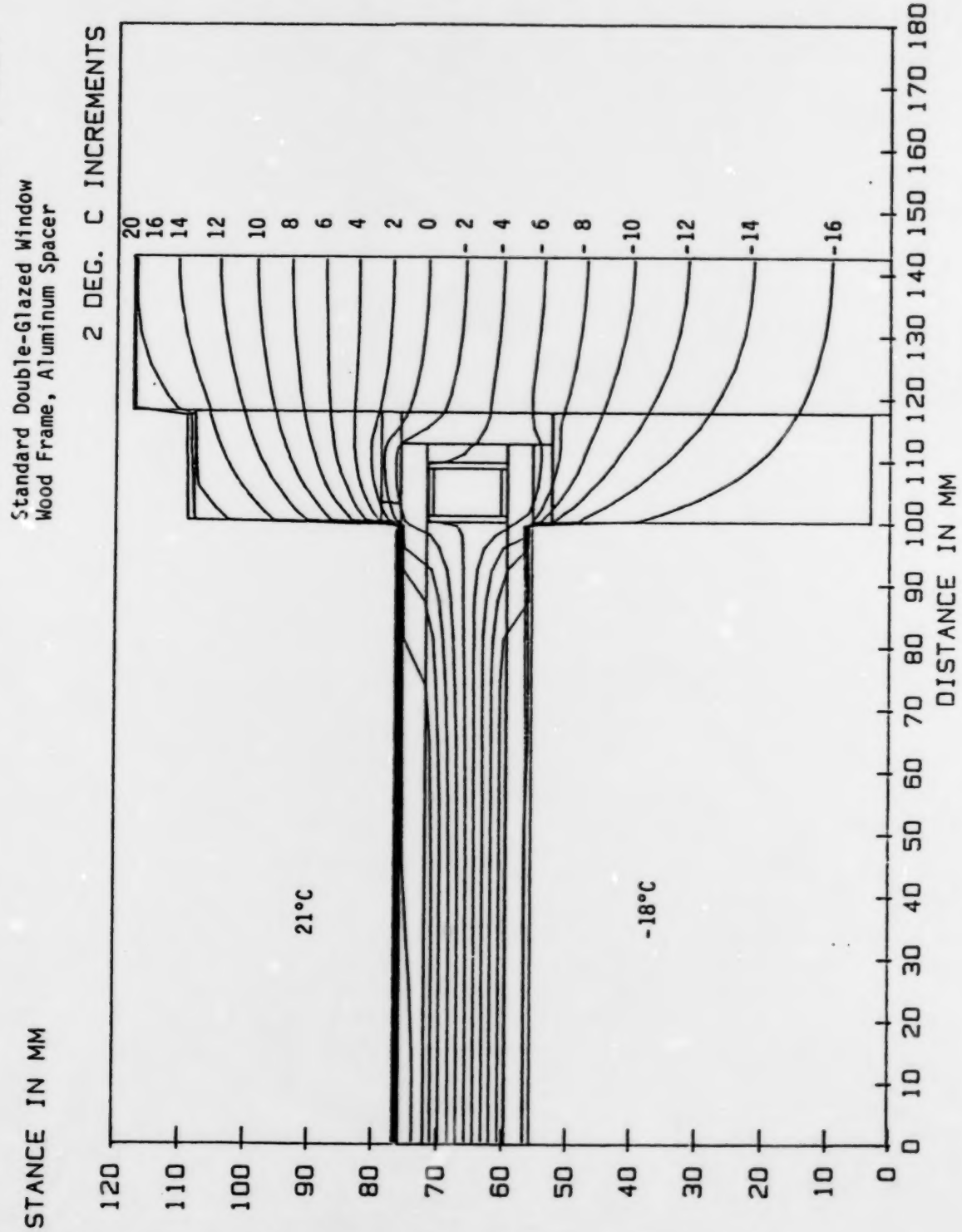


Figure 7. Wood Frame with Aluminum Spacer



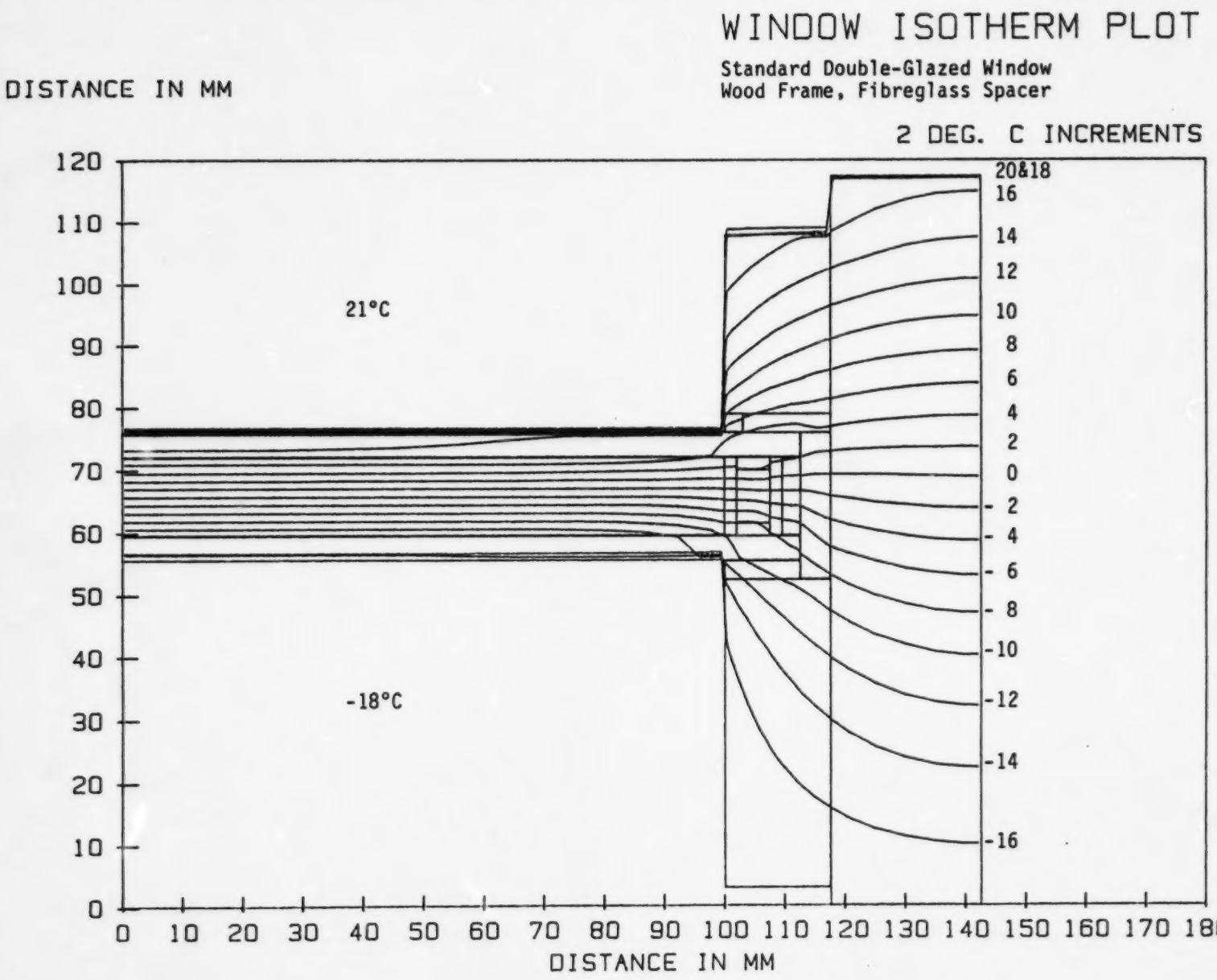


Figure 8. Wood Frame with Fiberglass Spacer

For the conditions examined, the average inner glazing edge temperature can be increased by up to seven degrees Celsius when the aluminum spacer is replaced with an improved spacer. The actual glazing temperature improvement will, however, vary significantly, depending on the imposed weather conditions and the location on the frame.

5.2 Glazing Type

The improvement in the thermal performance of windows, due to improved spacer or frame design, is even greater for high-efficiency windows. Table 4 and Figure 9 shows that the U-value of a window with low-emissivity glazings can be reduced by as much as 12 percent (compared with 6 percent for standard glazings), merely by replacing the aluminum spacer with a more effective material. This effect is even more pronounced for high performance windows, as shown in Table 5.

The dependence of frame heat loss on glazing type is illustrated graphically in Figure 11. This shows both net and gross frame heat loss for several different types of glazing. The net frame heat loss is the heat lost out the frame portion of the window and can be written as:

Net frame loss = $Q_3 + Q_4$ (see Appendix B).

The gross frame heat loss is the net frame heat loss plus the increased heat loss out the glazing due to the frame and spacer. The gross heat loss can be written as:

$$\text{Gross frame loss} = Q_{\text{total window}} - Q_{\text{at centre of glazing}} A_{\text{glazing}} (T_{in} - T_{out})$$

Although the net heat loss is relatively constant, the gross heat loss increases significantly as the thermal resistance of the window increases. If the U-value of the glazing is lower than that of the frame,

Table 4. Effect of Spacer Design on Low-ε Window U-Value *

Spacer Material	Glazing Area (%)	Overall Window Performance U-Value ($W/m^2/K$)	Adjustment Factor	Improvement (%)
Aluminum	80	2.14	1.17	base
Aluminum Double-Seal	80	2.05	1.12	4.2
Fiberglass	80	1.92	1.05	10.3
Butyl Rubber	80	1.91	1.04	10.7
Stainless Steel	80	1.87	1.02	12.6
Insulated	80	1.89	1.03	11.7
No Spacer	80	1.80	.98	15.9
Aluminum	85	2.08	1.14	base
Aluminum Double-Seal	85	2.01	1.10	3.4
Fiberglass	85	1.91	1.04	8.2
Butyl Rubber	85	1.89	1.03	9.1
Stainless Steel	85	1.87	1.02	10.1
Insulated	85	1.88	1.03	9.6
No Spacer	85	1.81	.99	13.0
Aluminum	90	2.01	1.10	base
Aluminum Double-Seal	90	1.96	1.07	2.5
Fiberglass	90	1.89	1.03	6.0
Butyl Rubber	90	1.88	1.03	6.5
Stainless Steel	90	1.86	1.02	7.5
Insulated	90	1.87	1.02	7.0
No Spacer	90	1.83	1.00	9.0
No Frame/No Spacer	100	1.83	1.00	-

* U-Value calculations presented for a wood frame and low-emissivity double-glazing.

Figure 9

EFFECT OF SPACER MATERIAL ON ADJUSTMENT FACTOR

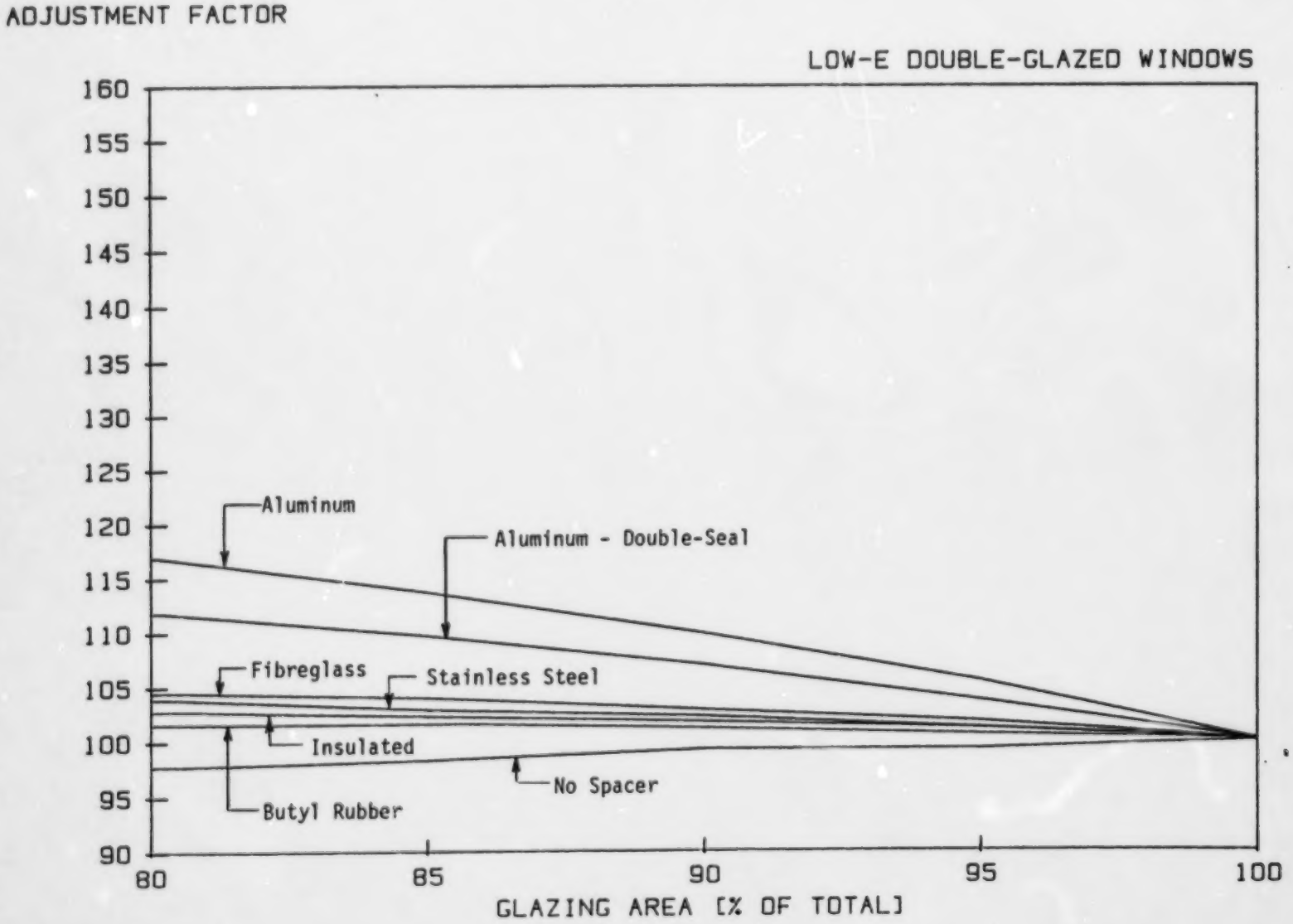


Table 5. Effect of Spacer Improvement on High-Performance Window U-Value

		Glazing Area (%)	Total Window U-Value		
			Aluminum Spacer	Insulated Spacer	Improvement (%)
1)	Standard Double Glazing	80	2.87	2.68	6.6
2)	Low-Emmissivity Double Glazing	80	2.14	1.89	11.7
3)	Standard Triple Glazing	80	2.13	1.85	13.1
4)	Triple Glazing - middle glazing low-ε coated polyester film (PET)	80	1.77	1.42	19.8
5)	Same as 4) with Krypton gas fill between glazings	80	1.52	1.25	17.8
				1.29 *	15.1

* Value for a hybrid spacer comprising of an insulated half-spacer and an aluminum half-spacer.

Figure 10

EFFECT OF GLAZING TYPE ON ADJUSTMENT FACTOR

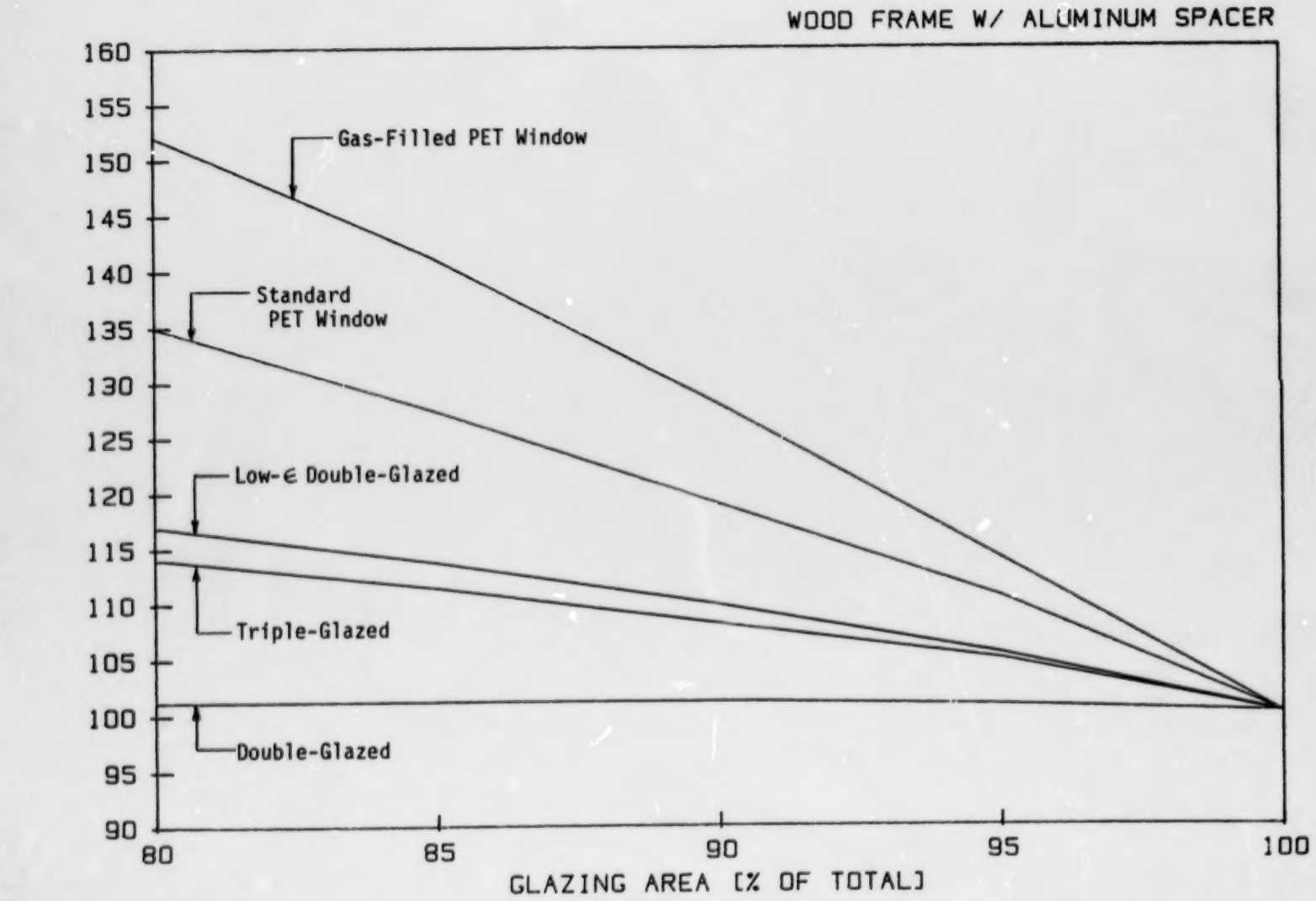
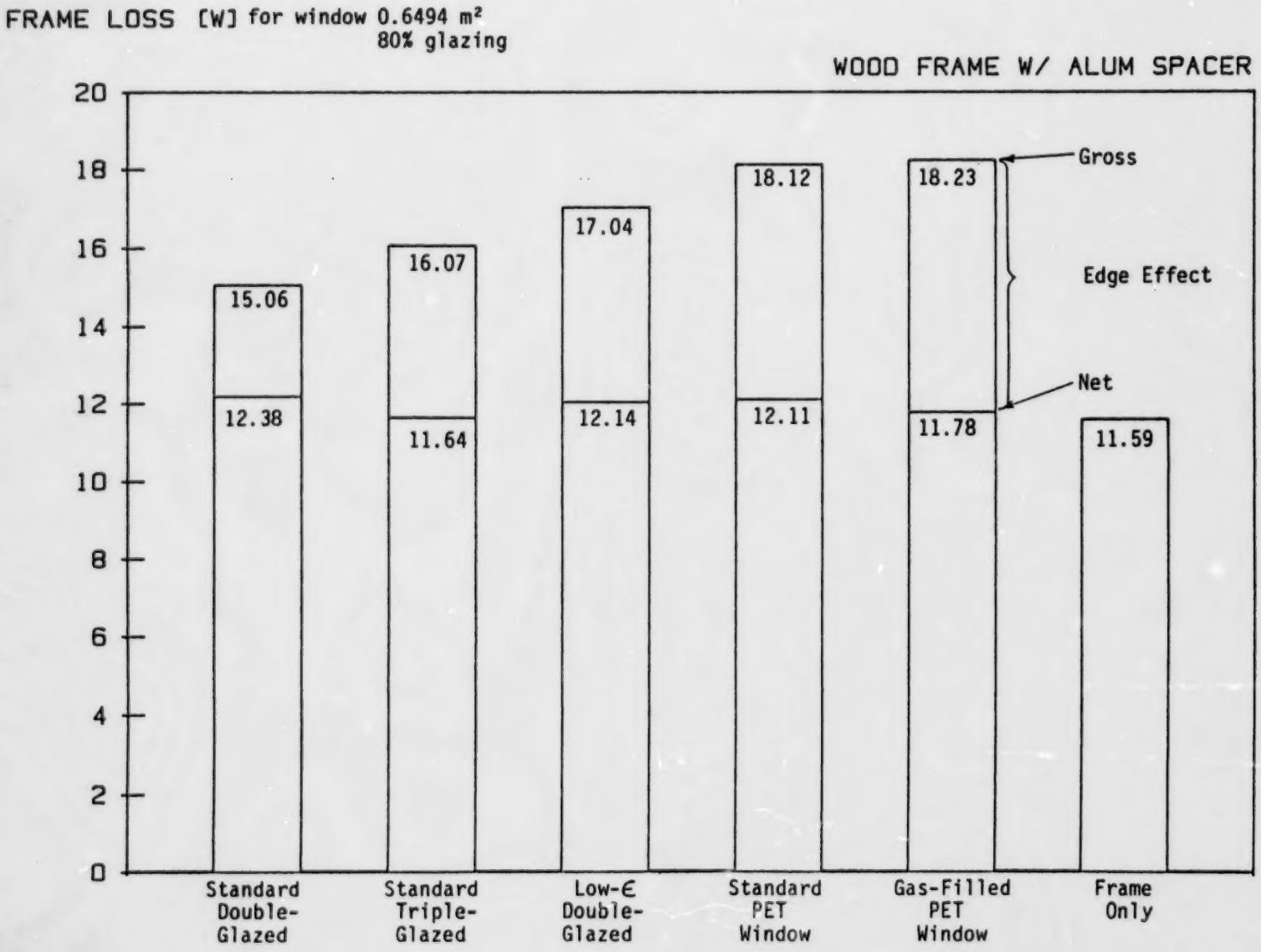


Figure 11

FRAME LOSS FOR SEVERAL GLAZING TYPES



(as is the case with low-emissivity glazings), the temperature of the inner glazing will be higher than that of the frame, and the temperature of the outer glazing will be lower. The result is that heat travels along the inner glazing, across the spacer and along the outer glazing to the outdoors. Therefore, the benefits associated with low-emissivity glazings can be negated by an aluminum spacer (or frame) that effectively provides a "thermal short-circuit" through the window.

In general, then, the thermal performance of the glazing and of the spacer/frame assembly are interdependent, and cannot be considered separately. Improving the glazing will not be very effective unless the spacer and frame are also upgraded.

5.3 Bite Design

The effect of incorporating a larger bite into the window frame design is shown in Table 6. The results are presented for a fixed glazing size. The windows with a larger bite (and therefore larger frame) will require a larger rough window opening and will have a smaller percentage glazing. In order to compare the windows on an equal percentage glazing and equal glazing size, a second base case is presented. This base case adds a strip of insulated wall to the window perimeter such that the total area is the same. The insulated wall is assumed to have a thermal resistance of 3.6 (m^2K/W), and heat flow through these sections is assumed to be one-dimensional.

Upon examination of the results shown in Table 6 it can be stated that a larger bite improves the thermal resistance of windows with poor (aluminum) spacers. However, if an improved spacer is used, a larger bite results in an increased U-value. Therefore it can be concluded that, in the design of new, advanced windows, the trend should be to produce thin frame profiles.

Table 6. Effect of Bite on Total Window U-Value for a Fixed Glazing Size

Frame Description	Spacer Material	Glazing Area (%)	U-Value ($W/m^2/K$)	Adjustment Factor	Improvement (%)
Wood - ½" bite	Aluminum	83.98	2.87	1.01	A
Wood - ½" bite/ Insulated Wall	Aluminum	80	2.75	0.97	B
Wood with a 1" bite	Aluminum	80	2.71	0.95	5.6 over A 1.5 over B
Wood - ½" bite	Fiberglass	83.98	2.73	0.96	A
Wood - ½" bite/ Insulated Wall	Fiberglass	80	2.59	0.91	B
Wood with a 1" bite	Fiberglass	80	2.64	0.93	3.3 over A -1.9 over B

5.4 Frame Design

It is evident from the results presented in Table 7 that the best combination of framing materials is PVC and polyurethane foam. While wood has the best thermal conductivity of the framing materials, its performance is limited by the fact that the inclusion of internal cavities is difficult. The performance of PVC and fiberglass, on the other hand, is dependent upon the number, size, and relative positioning of the internal cavities. Increasing the number of vertical partitions (i.e., perpendicular to the heat flow) has the effect of decreasing the effective conductivity of the air enclosures. Therefore, it may be possible to design a PVC or fiberglass frame with a U-value equivalent to a wood or polyurethane foam filled frame.

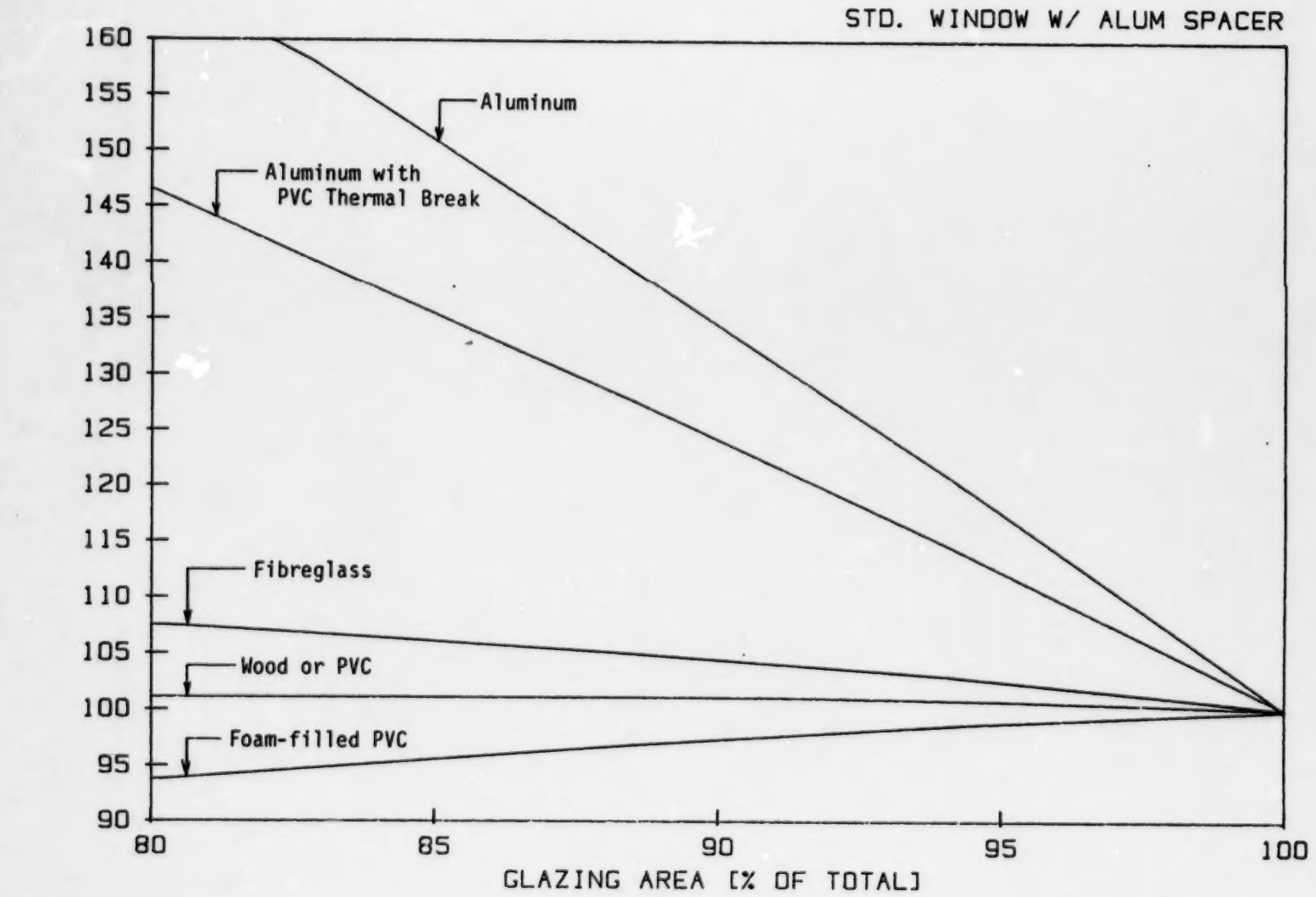
Figure 13 shows the window isotherm plot for the aluminum frame. Both the frame and spacer are essentially isothermal. When a PVC thermal break is incorporated into the frame (Figure 14), the temperature differential across the frame increases to approximately 14°C. This results in a 12 percent increase in overall window thermal resistance.

Table 7: Effect of Frame Design on Total Window U-Value

Frame Material	Spacer Material	Glazing Area (%)	U-Value (w/m^2K)	Adjustment Factor	Improvement (%)
Aluminum	Aluminum	80	4.72	1.67	base
Aluminum with Thermal Break	Aluminum	80	4.14	1.46	12.3
Fiberglass	Aluminum	80	3.05	1.07	35.9
PVC	Aluminum	80	2.87	1.01	39.2
Wood	Aluminum	80	2.87	1.01	39.2
PVC with Polyurethane Foam	Aluminum	80	2.66	0.94	43.6

Figure 12

EFFECT OF FRAME MATERIAL ON ADJUSTMENT FACTOR



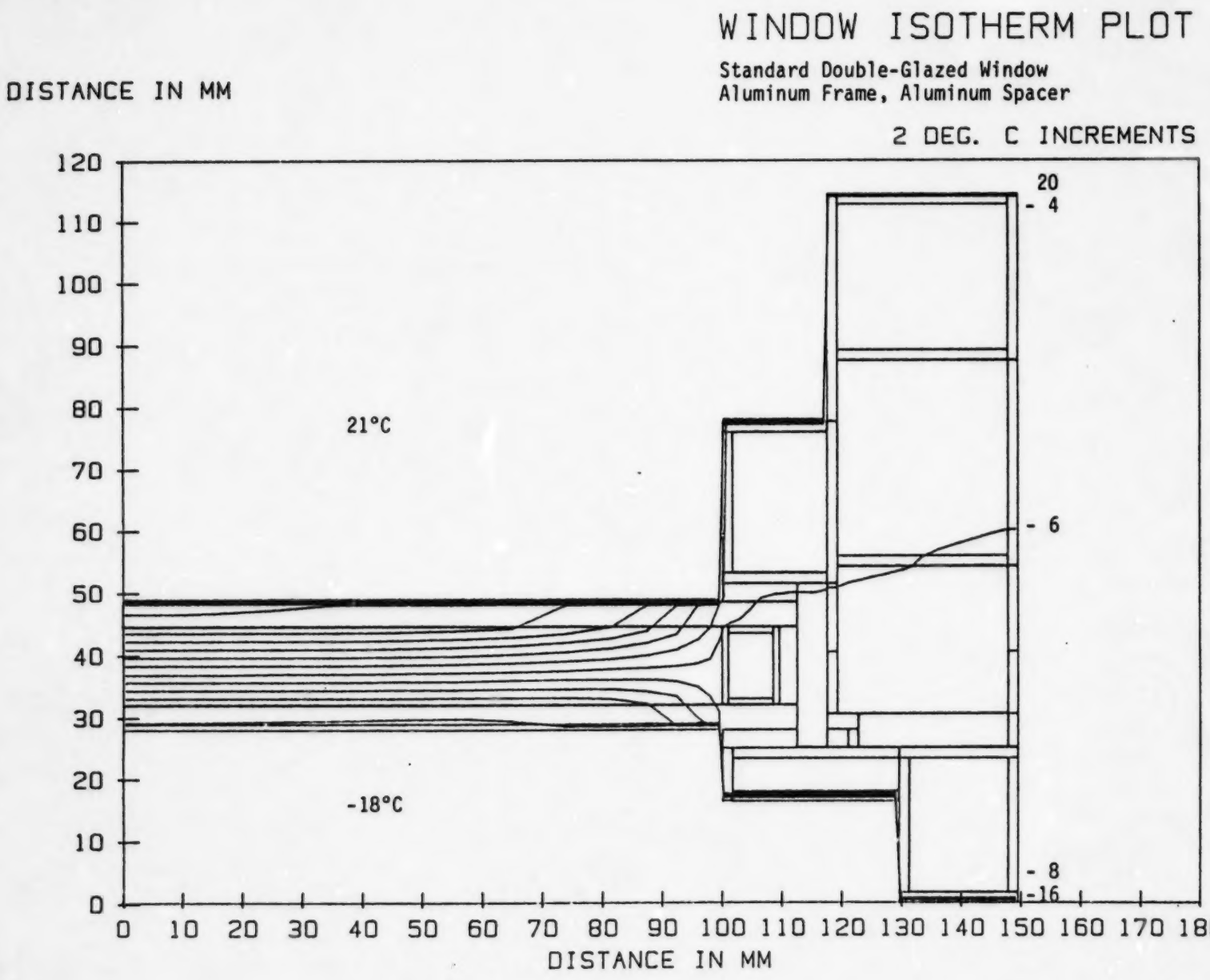


Figure13. Aluminum Frame

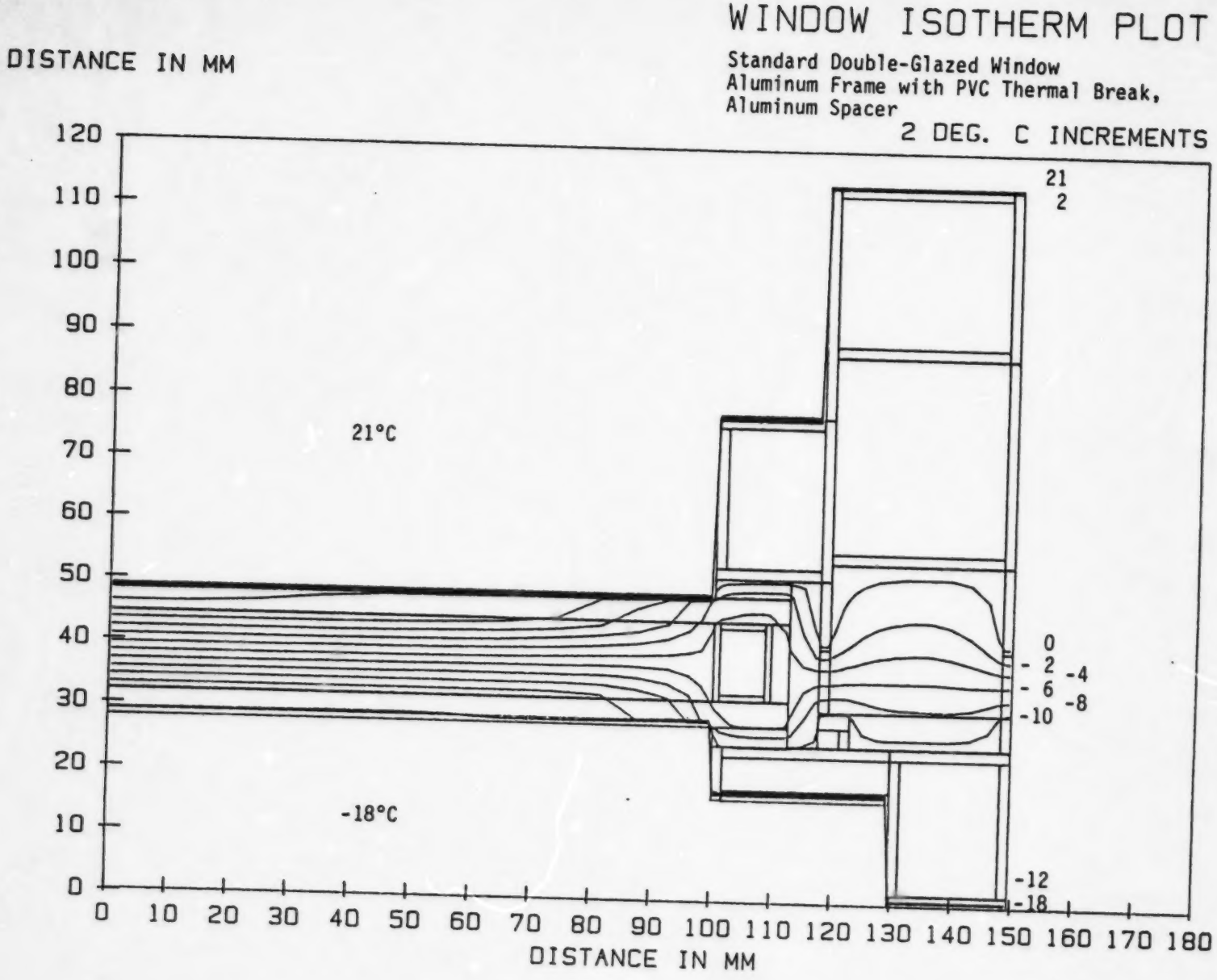


Figure 14. Aluminum Frame with PVC Thermal Break

6. CONCLUSIONS/RECOMMENDATIONS

6.1 Conclusions

The use of fiberglass, butyl rubber, or stainless steel as a spacer results in windows of nearly equivalent thermal resistance. Replacing aluminum spacers with either of these improved spacers has the effect of reducing the total window heat loss by three to six percent. This constitutes a twenty percent reduction in frame heat loss.

The use of an ideal or "perfect" spacer in the construction of window assemblies could decrease the total window U-value by eight percent as compared to an aluminum spacer. This represents a further decrease of 1.5 percent over the improved spacers.

The thermal performance of the glazing and the spacer/frame assembly cannot be considered separately, due to a conductive interaction between these elements. Benefits associated with high-performance glazings can be negated by poor selection of frame and/or spacer material.

Incorporating a larger bite in window frame construction has the effect of increasing total window resistance only when a highly conductive spacer is employed. When improved spacers, of relatively low thermal conductivity, are used, the overall window thermal resistance decreases.

The best combination of framing materials was determined to be a PVC frame with polyurethane foam filling the interior air cavities. The use of wood, fiberglass, or PVC as a framing material results in a significant improvement over aluminum windows (up to forty-three percent).

6.2 Recommendations

The **FRAME** computer program should be made accessible to window frame manufacturers through either the sale of the program or the establishment of a window frame analysis service.

While the program is extremely useful in its present form, further development is still required. Graphical input, onscreen graphical output (with the addition of heat flow plots), and simplification of the convergence technique are areas which demand attention.

Further studies should concentrate on the effect that various glazing technologies, coupled with advanced frame designs, have on window U-values. This analysis could be conducted in conjunction with the **VISION** program. The effect of incorporating a smaller bite and thinner profiles on the total window heat flow should also be investigated.

7. REFERENCES

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8. Roffeson, J.P., Canadian Solar Energy Review - March 1986, Solar Energy Program, National Research Council, May 1986, pg. 36.

9. ASHRAE Handbook of Fundamentals

10. Ontario Research Foundation, Comparative Heat Flow and Surface Temperature Measurements of Sealed Glass Units, prepared for Tremco Canada Ltd., December 13, 1984, Report No. 38-40159A.

APPENDIX A:

A TYPICAL PROGRAM OUTPUT

```
*****************************************
*                                       *
*              WINDOW FRAME             *
*            ANALYSIS PROGRAM           *
*                                       *
*****************************************

  INPUT FILE : alwal.DAT


          ********** INPUT DATA **********

IMAX   JMAX   LCOORD
 47     38       1

THE DISTANCE BETWEEN NODES

  1.00   2.00   1.00   5.00   5.00   5.00   5.00   5.00   5.00   5.00
  5.00   5.00   2.50   1.00   1.50   1.50   1.00   2.00   1.00    .50
   .50   1.00   1.00   2.00   2.50   2.00   1.00   1.00    .50    .50
  1.00   2.00   1.00   1.50   1.50   1.00   2.00   5.00   5.00   5.00
  5.00   5.00   1.00   3.00   3.00   2.50   1.00

THE DISTANCE BETWEEN NODES

  1.00   9.00  10.00  10.00  10.00  10.00  10.00  10.00   8.00   7.00
  5.00   5.00   2.00   2.00   1.00    .50    .50   1.00   1.00   1.80
  1.80   1.00   1.00    .50    .50   1.00   1.00   1.00   1.00   3.00
  1.00   1.00   4.00   5.00   5.00   5.00   4.00   1.00

SUBREGION  IMIN  JMIN  IMAX  JMAX      OMEGA    CONDUCTIVITY
     1      20    16    30    17       .0000     210.0000
     2      20    18    21    23       .0000     210.0000
     3      22    18    28    23       .0000        .0500
     4      29    18    30    23       .0000     210.0000
     5      20    24    30    25       .0000     210.0000
     6      20    26    30    28       .0000        .3000
     7      15    29    33    31       .0000        .0680
     8      31     1    33    28       .0000       1.0000
     9      20     1    30    15       .0000        .0710
    10      17     1    19    28       .0000       1.0000
    11      15    16    16    28       .0000        .1300
    12       3    16    14    31       .0000        .1400
    13      34    16    35    19       .0000        .1400
    14      34    20    35    31       .0000        .1300
    15      36    16    43    31       .0000        .1400
    16       1    32    47    38       .0000        .1400
```

BOUNDARY	IMIN	JMIN	IMAX	JMAX	R-VALUE	TEMPERATURE
1	17	1	33	1	9999.0000	.0000
2	33	1	33	16	.1320	21.0000
3	33	16	43	16	.1320	21.0000
4	43	16	43	32	.1320	21.0000
5	43	32	47	32	.1320	21.0000
6	47	32	47	38	.1320	21.0000
7	47	38	1	38	9999.0000	.0000
8	1	38	1	32	.0350	-18.0000
9	1	32	3	32	.0350	-18.0000
10	3	32	3	16	.0350	-18.0000
11	3	16	17	16	.0350	-18.0000
12	17	16	17	1	.0350	-18.0000

NUMBER OF INTERNAL POINTS WITH CONSTANT HEAT GENERATION IS 0
NUMBER OF INTERNAL POINTS WITH FIXED TEMPERATURES IS 0
THE NUMBER OF SEGMENTS WITH X-DIRECTED SPECIAL BOUNDARY TEMPERATURES IS 0
THE NUMBER OF SEGMENTS WITH Y-DIRECTED SPECIAL BOUNDARY TEMPERATURES IS 0
THE NUMBER OF SEGMENTS WITH X-DIRECTED CONSTANT BOUNDARY FLOW IS 0
THE NUMBER OF SEGMENTS WITH Y-DIRECTED CONSTANT BOUNDARY FLOW IS 0

********** RESULTS **********

THE NUMBER OF ITERATIONS = 2085
THE RELATIVE CONVERGENCE TOLERANCE = .005000

IA	LOMFIX(IA)	OMEGA(IA)	EPSK(IA)
1	0	.000	.0000
2	0	.000	.0000
3	0	.000	.0000
4	0	.000	.0000
5	0	.000	.0000
6	0	.000	.0000
7	0	.000	.0000
8	0	.000	.0000
9	0	.000	.0000
10	0	.000	.0000
11	0	.000	.0000
12	0	.000	.0000
13	0	.000	.0000
14	0	.000	.0000
15	0	.000	.0000
16	0	.000	.0000

********* BOUNDARIES *********

BOUNDARY				MEAN TEMP (Deg C)	TEMP ACROSS BOUND (Deg C)	MEAN FLOW (W/m2)	TOTAL FLOW (W)
17	1	33	1	-4.13	.00	.0004	.0000
33	1	33	16	4.93	21.00	-122.8573	-12.1629
33	16	43	16	11.72	21.00	74.4447	2.3078
43	16	43	32	16.60	21.00	-41.8232	-.6943
43	32	47	32	18.46	21.00	36.9783	.3143
47	32	47	38	17.01	21.00	-35.9100	-.8618
47	38	1	38	-2.93	.00	-.0003	.0000
1	38	1	32	-16.08	-16.00	-17.3548	-.4165
1	32	3	32	-52.68	-18.00	-34.2667	-.0343
3	32	3	16	-18.65	-18.00	-11.3075	-.1877
3	16	17	16	-16.57	-18.00	-53.2853	-2.7176
17	16	17	1	-13.50	-18.00	-131.9860	-13.0668

THE TOTAL FLOW INTO THE WINDOW IS 16.3411
THE TOTAL FLOW OUT OF THE WINDOW IS 16.4229

NET HEAT GAIN -.0818

******** TEMPERATURES ********

Z-DIST	R-DIST .0	.5	2.0	3.5	6.5	11.5	16.5	21.5	26.5
.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
.5	.00	.00	.00	.00	.00	.00	.00	.00	.00
5.5	.00	.00	.00	.00	.00	.00	.00	.00	.00
15.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
25.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
35.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
45.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
55.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
65.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
74.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
81.5	.00	.00	.00	.00	.00	.00	.00	.00	.00
87.5	.00	.00	.00	.00	.00	.00	.00	.00	.00
92.5	.00	.00	.00	.00	.00	.00	.00	.00	.00
96.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
98.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
99.5	.00	.00	.00	-18.00	-18.00	-18.00	-18.00	-18.00	-18.00
100.3	.00	.00	-18.00	-17.84	-17.75	-17.60	-17.43	-17.23	-16.99
100.7	.00	.00	-18.00	-17.83	-17.73	-17.56	-17.37	-17.16	-16.90
101.5	.00	.00	-18.00	-17.80	-17.67	-17.50	-17.29	-17.04	-16.78
102.3	.00	.00	-18.00	-17.77	-17.64	-17.42	-17.18	-16.90	-16.56
103.9	.00	.00	-18.00	-17.73	-17.58	-17.31	-17.03	-16.70	-16.30
105.7	.00	.00	-18.00	-17.68	-17.49	-17.18	-16.84	-16.45	-15.92
107.1	.00	.00	-18.00	-17.63	-17.43	-17.08	-16.70	-16.26	-15.74
108.1	.00	.00	-18.00	-17.61	-17.39	-17.01	-16.60	-16.13	-15.58
108.9	.00	.00	-18.00	-17.58	-17.35	-16.95	-16.52	-16.04	-15.46
109.4	.00	.00	-18.00	-17.57	-17.33	-16.92	-16.47	-15.97	-15.36
110.1	.00	.00	-18.00	-17.55	-17.30	-16.87	-16.40	-15.88	-15.27
111.1	.00	.00	-18.00	-17.52	-17.25	-16.80	-16.31	-15.76	-15.12
112.1	.00	.00	-18.00	-17.49	-17.21	-16.73	-16.22	-15.65	-14.97
113.1	.00	.00	-18.00	-17.47	-17.17	-16.67	-16.13	-15.53	-14.84
115.1	.00	.00	-18.00	-17.41	-17.08	-16.54	-15.96	-15.32	-14.57
117.1	.00	-18.00	-18.00	-17.35	-17.00	-16.42	-15.81	-15.13	-14.34
118.1	-18.00	-17.64	-17.52	-17.32	-16.96	-16.37	-15.74	-15.03	-14.23
120.6	-18.00	-17.51	-17.36	-17.20	-16.85	-16.23	-15.56	-14.82	-13.97
125.1	-18.00	-17.39	-17.22	-17.04	-16.68	-16.01	-15.29	-14.49	-13.60
130.1	-18.00	-17.32	-17.13	-16.94	-16.54	-15.84	-15.07	-14.23	-13.29
135.1	-18.00	-17.28	-17.08	-16.87	-16.45	-15.72	-14.92	-14.05	-13.10
139.6	-18.00	-17.26	-17.05	-16.84	-16.42	-15.67	-14.86	-13.98	-13.01
142.1	-18.00	-17.26	-17.05	-16.84	-16.41	-15.66	-14.83	-13.97	-13.00
142.6	.00	.00	.00	.00	.00	.00	.00	.00	.00

******** TEMPERATURES ********

Z-DIST	R-DIST 31.5	36.5	41.5	46.5	50.3	52.0	53.2	54.7	56.0
.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
.5	.00	.00	.00	.00	.00	.00	.00	-18.00	-14.07
5.5	.00	.00	.00	.00	.00	.00	.00	-18.00	-14.07
15.0	.00	.00	.00	.00	.00	.00	.00	-18.00	-14.07
25.0	.00	.00	.00	.00	.00	.00	.00	-18.00	-14.08
35.0	.00	.00	.00	.00	.00	.00	.00	-18.00	-14.08
45.0	.00	.00	.00	.00	.00	.00	.00	-18.00	-14.08
55.0	.00	.00	.00	.00	.00	.00	.00	-18.00	-14.05
65.0	.00	.00	.00	.00	.00	.00	.00	-18.00	-13.92
74.0	.00	.00	.00	.00	.00	.00	.00	-18.00	-13.59
81.5	.00	.00	.00	.00	.00	.00	.00	-18.00	-12.95
87.5	.00	.00	.00	.00	.00	.00	.00	-18.00	-11.93
92.5	.00	.00	.00	.00	.00	.00	.00	-18.00	-10.53
96.0	.00	.00	.00	.00	.00	.00	.00	-18.00	-8.96
98.0	.00	.00	.00	.00	.00	.00	.00	-18.00	-7.92
99.5	-18.00	-18.00	-18.00	-18.00	-18.00	-18.00	-18.00	-18.00	-7.06
100.3	-16.69	-16.28	-15.67	-14.67	-13.23	-12.15	-11.14	-9.06	-6.68
100.7	-16.57	-16.12	-15.45	-14.36	-12.79	-11.62	-10.51	-8.39	-6.42
101.5	-16.38	-15.87	-15.13	-13.90	-12.17	-10.89	-9.71	-7.62	-6.05
102.5	-16.14	-15.56	-14.71	-13.34	-11.44	-10.10	-8.90	-6.97	-5.67
103.9	-15.80	-15.13	-14.16	-12.62	-10.57	-9.22	-8.05	-6.33	-5.26
105.7	-15.40	-14.62	-13.52	-11.84	-9.74	-8.45	-7.38	-5.87	-4.96
107.1	-15.10	-14.26	-13.08	-11.35	-9.29	-8.06	-7.05	-5.67	-4.87
108.1	-14.90	-14.01	-12.80	-11.04	-9.02	-7.84	-6.88	-5.58	-4.82
108.9	-14.75	-13.83	-12.59	-10.83	-8.86	-7.72	-6.80	-5.54	-4.81
109.4	-14.65	-13.72	-12.47	-10.70	-8.77	-7.65	-6.75	-5.53	-4.81
110.1	-14.51	-13.55	-12.28	-10.53	-8.64	-7.57	-6.70	-5.51	-4.82
111.1	-14.33	-13.34	-12.05	-10.32	-8.53	-7.52	-6.69	-5.54	-4.85
112.1	-14.16	-13.15	-11.84	-10.13	-8.45	-7.53	-6.73	-5.61	-4.89
113.1	-14.00	-12.96	-11.65	-9.97	-8.39	-7.63	-6.87	-5.85	-5.19
115.1	-13.69	-12.62	-11.29	-9.68	-8.30	-7.71	-7.10	-6.30	-5.76
117.1	-13.42	-12.33	-11.01	-9.44	-8.14	-7.57	-7.02	-6.35	-5.86
118.1	-13.30	-12.19	-10.87	-9.33	-8.05	-7.44	-6.94	-6.34	-5.88
120.6	-13.00	-11.87	-10.56	-9.07	-7.83	-7.23	-6.89	-6.28	-5.85
125.1	-12.58	-11.44	-10.14	-8.70	-7.53	-6.97	-6.57	-6.08	-5.68
130.1	-12.25	-11.10	-9.81	-8.41	-7.28	-6.74	-6.35	-5.88	-5.48
135.1	-12.04	-10.88	-9.60	-8.22	-7.12	-6.59	-6.20	-5.74	-5.34
139.6	-11.95	-10.78	-9.51	-8.14	-7.04	-6.51	-6.13	-5.67	-5.27
142.1	-11.94	-10.77	-9.50	-8.13	-7.03	-6.50	-6.12	-5.66	-5.27
142.6	.00	.00	.00	.00	.00	.00	.00	.00	.00

******** TEMPERATURES ********

Z-DIST	R-DIST 57.5	59.0	59.7	60.2	61.0	62.0	63.5	65.7	68.0
.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
.5	-13.91	-13.74	-13.29	-12.51	-11.34	-9.78	-7.44	-3.93	-.42
5.5	-13.91	-13.74	-13.29	-12.51	-11.34	-9.78	-7.44	-3.93	-.42
15.0	-13.91	-13.74	-13.30	-12.52	-11.35	-9.79	-7.45	-3.95	-.44
25.0	-13.91	-13.75	-13.30	-12.53	-11.36	-9.80	-7.47	-3.97	-.47
35.0	-13.92	-13.75	-13.31	-12.54	-11.37	-9.83	-7.50	-4.02	-.53
45.0	-13.92	-13.75	-13.31	-12.54	-11.39	-9.85	-7.55	-4.09	-.63
55.0	-13.88	-13.72	-13.29	-12.53	-11.39	-9.88	-7.60	-4.20	-.79
65.0	-13.76	-13.59	-13.17	-12.44	-11.33	-9.86	-7.65	-4.35	-1.04
74.0	-13.41	-13.26	-12.85	-12.15	-11.11	-9.71	-7.63	-4.52	-1.41
81.5	-12.76	-12.60	-12.23	-11.59	-10.62	-9.35	-7.46	-4.64	-1.83
87.5	-11.70	-11.55	-11.22	-10.65	-9.81	-8.70	-7.06	-4.65	-2.28
92.5	-10.26	-10.10	-9.82	-9.35	-8.64	-7.74	-6.43	-4.57	-2.74
96.0	-8.63	-8.45	-8.20	-7.80	-7.22	-6.53	-5.60	-4.39	-3.21
98.0	-7.52	-7.24	-6.99	-6.59	-6.09	-5.57	-4.96	-4.25	-3.58
99.5	-6.57	-5.95	-5.49	-5.07	-4.74	-4.53	-4.34	-4.14	-3.94
100.3	-6.12	-5.09	-4.18	-4.17	-4.16	-4.15	-4.13	-4.10	-4.07
100.7	-5.85	-4.81	-4.18	-4.18	-4.17	-4.15	-4.13	-4.10	-4.07
101.5	-5.52	-4.56	-4.18	-4.18	-4.17	-4.15	-4.13	-4.10	-4.07
102.5	-5.21	-4.46	-4.18	-4.18	-4.17	-4.15	-4.13	-4.10	-4.06
103.9	-4.90	-4.37	-4.18	-4.18	-4.17	-4.15	-4.13	-4.09	-4.06
105.7	-4.69	-4.31	-4.17	-4.17	-4.15	-4.15	-4.12	-4.09	-4.05
107.1	-4.62	-4.28	-4.16	-4.16	-4.16	-4.14	-4.12	-4.09	-4.06
108.1	-4.59	-4.28	-4.16	-4.16	-4.15	-4.13	-4.11	-4.09	-4.06
108.9	-4.60	-4.29	-4.15	-4.15	-4.14	-4.13	-4.11	-4.09	-4.06
109.4	-4.61	-4.33	-4.15	-4.15	-4.14	-4.13	-4.11	-4.09	-4.06
110.1	-4.64	-4.44	-4.33	-4.26	-4.20	-4.16	-4.11	-4.08	-4.01
111.1	-4.68	-4.53	-4.45	-4.37	-4.28	-4.20	-4.11	-4.02	-3.91
112.1	-4.71	-4.57	-4.50	-4.42	-4.32	-4.22	-4.11	-3.97	-3.83
113.1	-4.84	-4.63	-4.53	-4.45	-4.34	-4.22	-4.06	-3.85	-3.63
115.1	-5.23	-4.83	-4.65	-4.54	-4.38	-4.17	-3.88	-3.47	-3.03
117.1	-5.33	-4.88	-4.67	-4.53	-4.32	-4.06	-3.68	-3.11	-2.52
118.1	-5.35	-4.88	-4.66	-4.51	-4.30	-4.01	-3.60	-2.98	-2.34
120.6	-5.34	-4.86	-4.62	-4.47	-4.23	-3.93	-3.47	-2.78	-2.07
125.1	-5.19	-4.70	-4.46	-4.30	-4.05	-3.73	-3.24	-2.50	-1.74
130.1	-5.00	-4.52	-4.27	-4.11	-3.86	-3.53	-3.03	-2.27	-1.50
135.1	-4.86	-4.38	-4.13	-3.97	-3.72	-3.39	-2.89	-2.13	-1.35
139.6	-4.80	-4.31	-4.07	-3.91	-3.66	-3.33	-2.83	-2.06	-1.28
142.1	-4.79	-4.31	-4.06	-3.90	-3.65	-3.32	-2.82	-2.06	-1.26
142.6	.00	.00	.00	.00	.00	.00	.00	.00	.00

******** TEMPERATURES ********

Z-DIST	R-DIST 69.5	70.5	71.2	71.7	72.5	74.0	75.5	76.7	78.2
.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
.5	1.92	3.48	4.65	5.43	5.86	6.04	6.21	21.00	.00
5.5	1.92	3.48	4.65	5.43	5.88	6.04	6.21	21.00	.00
15.0	1.90	3.46	4.63	5.41	5.86	6.02	6.19	21.00	.00
25.0	1.87	3.42	4.59	5.37	5.81	5.98	6.15	21.00	.00
35.0	1.80	3.35	4.51	5.29	5.73	5.90	6.07	21.00	.00
45.0	1.68	3.22	4.38	5.15	5.59	5.76	5.93	21.00	.00
55.0	1.49	3.01	4.15	4.91	5.34	5.51	5.68	21.00	.00
65.0	1.16	2.64	3.75	4.49	4.91	5.07	5.24	21.00	.00
74.0	.67	2.06	3.11	3.81	4.21	4.37	4.54	21.00	.00
81.5	.05	1.31	2.25	2.89	3.25	3.40	3.59	21.00	.00
87.5	-.68	.39	1.20	1.75	2.06	2.20	2.39	21.00	.00
92.5	-1.50	-.66	-.01	.43	.68	.81	1.01	21.00	.00
96.0	-2.36	-1.74	-1.24	-.89	-.69	-.55	-.33	21.00	.00
98.0	-3.03	-2.59	-2.17	-1.84	-1.64	-1.43	-1.16	21.00	.00
99.5	-3.77	-3.60	-3.33	-3.00	-2.82	-2.14	-1.76	21.00	21.00
100.3	-4.05	-4.03	-4.02	-4.02	-3.29	-2.46	-1.99	.05	2.51
100.7	-4.05	-4.03	-4.02	-4.02	-3.51	-2.65	-2.16	-.36	2.08
101.5	-4.04	-4.03	-4.01	-4.01	-3.68	-2.89	-2.40	-.84	1.52
102.5	-4.04	-4.02	-4.01	-4.01	-3.77	-3.11	-2.66	-1.27	.77
103.9	-4.04	-4.02	-4.01	-4.01	-3.83	-3.32	-2.94	-1.70	.39
105.7	-4.04	-4.02	-4.01	-4.01	-3.87	-3.44	-3.11	-2.00	-.06
107.1	-4.04	-4.03	-4.02	-4.02	-3.87	-3.46	-3.15	-2.09	-.24
108.1	-4.04	-4.03	-4.02	-4.02	-3.86	-3.44	-3.13	-2.10	-.31
108.9	-4.05	-4.04	-4.03	-4.03	-3.92	-3.39	-3.10	-2.08	-.32
109.4	-4.05	-4.04	-4.03	-4.03	-3.76	-3.35	-3.06	-2.05	-.31
110.1	-3.96	-3.91	-3.82	-3.72	-3.56	-3.27	-3.00	-1.98	-.27
111.1	-3.81	-3.71	-3.59	-3.49	-3.38	-3.17	-2.89	-1.81	-.14
112.1	-3.69	-3.57	-3.44	-3.35	-3.27	-3.08	-2.78	-1.50	.06
113.1	-3.44	-3.29	-3.16	-3.07	-2.95	-2.64	-1.95	-.84	.40
115.1	-2.70	-2.45	-2.24	-2.09	-1.85	-1.28	-.40	.25	1.05
117.1	-2.09	-1.79	-1.54	-1.37	-1.11	-.52	.22	.75	1.43
118.1	-1.88	-1.56	-1.31	-1.13	-.86	-.28	.37	.89	1.57
120.6	-1.58	-1.23	-.97	-.79	-.51	.06	.67	1.19	1.84
125.1	-1.21	-.86	-.59	-.40	-.13	.44	1.02	1.52	2.13
130.1	-.97	-.61	-.34	-.16	.12	.67	1.24	1.72	2.30
135.1	-.82	-.46	-.19	-.01	.26	.81	1.36	1.83	2.40
139.6	-.76	-.40	-.13	.05	.32	.86	1.41	1.88	2.44
142.1	-.75	-.39	-.13	.05	.32	.87	1.42	1.88	2.44
142.6	.00	.00	.00	.00	.00	.00	.00	.00	.00

******** TEMPERATURES ********

Z-DIST	R-DIST 79.5	81.0	84.5	89.5	94.5	99.5	104.5	107.5	109.5
.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
.5	.00	.00	.00	.00	.00	.00	.00	.00	.00
5.5	.00	.00	.00	.00	.00	.00	.00	.00	.00
15.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
25.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
35.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
45.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
55.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
65.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
74.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
81.5	.00	.00	.00	.00	.00	.00	.00	.00	.00
87.5	.00	.00	.00	.00	.00	.00	.00	.00	.00
92.5	.00	.00	.00	.00	.00	.00	.00	.00	.00
96.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
98.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
99.5	21.00	21.00	21.00	21.00	21.00	21.00	21.00	21.00	.00
100.3	4.08	5.71	8.71	11.53	13.57	15.14	16.42	17.06	21.00
100.7	3.67	5.33	8.40	11.29	13.37	14.99	16.29	16.96	21.00
101.5	3.12	4.81	7.95	10.93	13.09	14.76	16.12	16.80	21.00
102.5	2.54	4.22	7.42	10.49	12.73	14.47	15.89	16.61	21.00
103.9	1.91	3.54	6.75	9.92	12.26	14.09	15.58	16.34	21.00
105.7	1.38	2.93	6.08	9.29	11.72	13.63	15.22	16.03	21.00
107.1	1.14	2.63	5.68	8.89	11.35	13.32	14.96	15.80	21.00
108.1	1.03	2.47	5.45	8.63	11.10	13.10	14.78	15.65	21.00
108.9	.99	2.40	5.30	8.45	10.93	12.95	14.66	15.54	21.00
109.4	.98	2.36	5.22	8.34	10.82	12.85	14.57	15.47	21.00
110.1	.98	2.32	5.10	8.19	10.66	12.71	14.46	15.37	21.00
111.1	1.05	2.33	4.98	8.01	10.47	12.53	14.31	15.24	21.00
112.1	1.19	2.37	4.90	7.85	10.30	12.37	14.17	15.12	21.00
113.1	1.37	2.46	4.84	7.71	10.14	12.21	14.03	15.01	21.00
115.1	1.79	2.67	4.76	7.47	9.84	11.92	13.79	14.80	21.00
117.1	2.07	2.85	4.74	7.31	9.62	11.69	13.58	14.68	21.00
118.1	2.17	2.92	4.74	7.24	9.52	11.58	13.47	14.65	15.63
120.6	2.40	3.09	4.74	7.08	9.28	11.31	13.21	14.33	15.07
125.1	2.64	3.27	4.77	6.91	8.98	10.94	12.77	13.79	14.46
130.1	2.79	3.39	4.79	6.80	8.76	10.64	12.41	13.39	14.03
135.1	2.87	3.45	4.80	6.73	8.62	10.45	12.18	13.14	13.78
139.6	2.91	3.47	4.80	6.70	8.57	10.37	12.08	13.04	13.67
142.1	2.91	3.47	4.80	6.70	8.56	10.36	12.07	13.03	13.66
142.6	.00	.00	.00	.00	.00	.00	.00	.00	.00

HEAT FLOW IN POSITIVE X-DIRECTION (W/M2)

Z-DIST	R-DIST .0	1.0	3.0	4.0	9.0	14.0	19.0	24.0
.5	.00	.00	.00	.00	.00	.00	.00	.00
5.5	.00	.00	.00	.00	.00	.00	.00	.00
15.0	.00	.00	.00	.00	.00	.00	.00	.00
25.0	.00	.00	.00	.00	.00	.00	.00	.00
35.0	.00	.00	.00	.00	.00	.00	.00	.00
45.0	.00	.00	.00	.00	.00	.00	.00	.00
55.0	.00	.00	.00	.00	.00	.00	.00	.00
65.0	.00	.00	.00	.00	.00	.00	.00	.00
74.0	.00	.00	.00	.00	.00	.00	.00	.00
81.5	.00	.00	.00	.00	.00	.00	.00	.00
87.5	.00	.00	.00	.00	.00	.00	.00	.00
92.5	.00	.00	.00	.00	.00	.00	.00	.00
96.0	.00	.00	.00	.00	.00	.00	.00	.00
98.0	.00	.00	.00	.00	.00	.00	.00	.00
99.5	.00	.00	.00	.00	.00	.00	.00	.00
100.3	.00	.00	-4.13	-4.16	-4.36	-4.77	-5.48	-6.61
100.7	.00	.00	-4.53	-4.56	-4.79	-5.23	-6.01	-7.25
101.5	.00	.00	-5.13	-5.16	-5.41	-5.92	-6.79	-8.19
102.5	.00	.00	-5.92	-5.96	-6.24	-6.82	-7.81	-9.41
103.9	.00	.00	-7.02	-7.06	-7.39	-8.06	-9.21	-11.06
105.7	.00	.00	-8.41	-8.45	-8.81	-9.59	-10.92	-13.05
107.1	.00	.00	-9.47	-9.51	-9.86	-10.72	-12.18	-14.48
108.1	.00	.00	-10.22	-10.26	-10.62	-11.50	-13.04	-15.45
108.9	.00	.00	-10.77	-10.81	-11.17	-12.07	-13.65	-16.14
109.4	.00	.00	-11.14	-11.18	-11.52	-12.44	-14.06	-16.58
110.1	.00	.00	-11.69	-11.73	-12.05	-12.98	-14.65	-17.23
111.1	.00	.00	-12.42	-12.44	-12.72	-13.68	-15.40	-18.05
112.1	.00	.00	-13.14	-13.15	-13.37	-14.35	-16.12	-18.81
113.1	.00	.00	-13.86	-13.85	-13.99	-14.98	-16.79	-19.53
115.1	.00	.00	-15.31	-15.21	-15.16	-16.19	-18.08	-20.87
117.1	.00	.00	-16.86	-16.39	-16.08	-17.19	-19.14	-21.94
118.1	-9.32	-11.34	-18.93	-16.84	-16.48	-17.66	-19.64	-22.43
120.6	-13.70	-13.63	-15.77	-16.28	-17.32	-18.75	-20.80	-23.56
125.1	-15.71	-16.02	-16.75	-17.09	-18.57	-20.25	-22.38	-25.07
130.1	-17.60	-17.77	-18.18	-18.41	-19.77	-21.47	-23.58	-26.13
135.1	-18.73	-18.86	-19.18	-19.37	-20.61	-22.27	-24.33	-26.77
139.6	-19.22	-19.34	-19.64	-19.82	-21.01	-22.63	-24.66	-27.05
142.1	-19.28	-19.39	-19.69	-19.86	-21.05	-22.67	-24.69	-27.08

HEAT FLOW IN POSITIVE X-DIRECTION (W/M2)

Z-DIST	R-DIST 29.0	34.0	39.0	44.0	49.0	51.5	52.5	54.0	55.5
.5	.00	.00	.00	.00	.00	.00	.00	.00	-110.65
5.5	.00	.00	.00	.00	.00	.00	.00	.00	-110.64
15.0	.00	.00	.00	.00	.00	.00	.00	.00	-110.57
25.0	.00	.00	.00	.00	.00	.00	.00	.00	-110.44
35.0	.00	.00	.00	.00	.00	.00	.00	.00	-110.31
45.0	.00	.00	.00	.00	.00	.00	.00	.00	-110.40
55.0	.00	.00	.00	.00	.00	.00	.00	.00	-111.34
65.0	.00	.00	.00	.00	.00	.00	.00	.00	-114.82
74.0	.00	.00	.00	.00	.00	.00	.00	.00	-124.19
81.5	.00	.00	.00	.00	.00	.00	.00	.00	-142.16
87.5	.00	.00	.00	.00	.00	.00	.00	.00	-171.06
92.5	.00	.00	.00	.00	.00	.00	.00	.00	-210.49
96.0	.00	.00	.00	.00	.00	.00	.00	.00	-254.64
98.0	.00	.00	.00	.00	.00	.00	.00	.00	-284.03
99.5	.00	.00	.00	.00	.00	.00	.00	.00	-307.65
100.3	-8.43	-11.49	-16.99	-28.05	-53.96	-86.40	-108.26	-179.74	-379.36
100.7	-9.24	-12.58	-18.59	-30.62	-58.68	-93.51	-118.37	-184.22	-313.59
101.5	-10.43	-14.17	-20.89	-34.24	-64.92	-101.84	-127.08	-180.36	-250.68
102.5	-11.96	-16.18	-23.69	-38.36	-70.95	-106.97	-128.73	-167.63	-207.50
103.9	-14.00	-18.81	-27.21	-43.16	-76.44	-108.27	-124.43	-149.21	-170.54
105.7	-16.38	-21.73	-30.76	-47.07	-78.24	-103.60	-114.85	-130.49	-142.93
107.1	-18.03	-23.62	-32.79	-48.62	-77.01	-98.39	-107.42	-119.52	-128.92
108.1	-19.13	-24.83	-33.97	-49.22	-75.36	-94.40	-102.36	-112.69	-120.92
108.9	-19.89	-25.64	-34.67	-49.34	-73.65	-91.26	-98.60	-106.75	-116.15
109.4	-20.38	-26.14	-35.08	-49.33	-72.36	-89.09	-96.51	-106.27	-113.43
110.1	-21.08	-26.85	-35.62	-49.18	-70.22	-85.68	-93.19	-102.98	-110.20
111.1	-21.95	-27.67	-36.14	-48.67	-66.84	-80.37	-89.13	-99.73	-109.46
112.1	-22.73	-28.38	-36.51	-47.94	-62.98	-73.14	-85.96	-96.87	-115.47
113.1	-23.45	-29.00	-36.74	-47.07	-58.84	-60.91	-52.42	-45.89	-35.98
115.1	-24.76	-30.05	-36.99	-45.21	-51.38	-47.11	-41.79	-36.32	-29.51
117.1	-25.73	-30.71	-36.93	-43.84	-48.63	-45.69	-37.52	-30.37	-26.43
118.1	-26.17	-30.99	-36.88	-43.24	-47.82	-48.98	-55.97	-55.77	-51.81
120.6	-27.16	-31.58	-36.69	-41.92	-46.10	-47.87	-48.68	-48.91	-48.92
125.1	-28.34	-32.14	-36.28	-40.31	-43.61	-44.79	-45.13	-45.47	-45.58
130.1	-29.12	-32.44	-35.91	-39.24	-42.09	-43.22	-43.61	-44.14	-44.59
135.1	-29.56	-32.58	-35.69	-38.67	-41.33	-42.49	-42.93	-43.55	-44.14
139.6	-29.74	-32.64	-35.59	-38.44	-41.05	-42.22	-42.67	-43.33	-43.96
142.1	-29.76	-32.64	-35.58	-38.42	-41.01	-42.20	-42.65	-43.31	-43.94

HEAT FLOW IN POSITIVE X-DIRECTION (W/M2)

Z-DIST	R-DIST 56.5	58.5	59.5	60.0	60.5	61.5	62.5	64.5	67.0
.5	-110.67	-110.73	-110.76	-110.76	-110.76	-110.77	-110.77	-110.78	-110.80
5.5	-110.67	-110.73	-110.75	-110.76	-110.76	-110.76	-110.76	-110.78	-110.80
15.0	-110.59	-110.64	-110.66	-110.66	-110.66	-110.67	-110.67	-110.69	-110.71
25.0	-110.43	-110.43	-110.43	-110.43	-110.43	-110.44	-110.44	-110.46	-110.49
35.0	-110.23	-110.07	-110.00	-109.99	-109.99	-109.99	-110.00	-110.02	-110.07
45.0	-110.10	-109.49	-109.18	-109.17	-109.17	-109.16	-109.15	-109.17	-109.24
55.0	-110.44	-108.59	-107.67	-107.64	-107.61	-107.57	-107.54	-107.53	-107.61
65.0	-112.36	-107.30	-104.77	-104.69	-104.61	-104.48	-104.37	-104.27	-104.32
74.0	-118.17	-105.81	-99.63	-99.42	-99.22	-98.88	-98.59	-98.22	-98.16
81.5	-129.87	-104.60	-91.96	-91.53	-91.12	-90.38	-89.76	-88.90	-88.57
87.5	-149.22	-104.20	-81.56	-80.78	-80.04	-78.68	-77.51	-75.81	-75.06
92.5	-176.90	-106.12	-69.20	-67.90	-66.61	-64.14	-61.96	-58.80	-57.60
96.0	-217.65	-125.45	-60.09	-57.51	-54.67	-48.92	-44.13	-38.32	-37.04
98.0	-265.33	-187.90	-62.47	-55.54	-48.19	-36.42	-28.90	-22.36	-21.40
99.5	-341.21	-408.23	-116.38	-59.09	-31.59	-14.31	-8.99	-6.53	-6.27
100.3	-379.19	-681.08	-1824.94	-2079.22	-2027.97	-2834.05	-2906.15	-2969.45	-2982.00
100.7	-379.33	-697.48	-1250.70	-1778.21	-2887.65	-2854.78	-2903.74	-2967.01	-2979.16
101.5	-356.23	-623.50	-799.35	-534.52	-1.27	-.93	-.83	-.81	-.81
102.5	-306.72	-496.64	-552.98	-261.95	-1.18	-1.00	-.90	-.83	-.83
103.9	-241.43	-354.95	-372.52	-150.80	-1.10	-1.01	-.93	-.84	-.84
105.7	-188.09	-257.16	-266.18	-96.13	-1.02	-.94	-.88	-.80	-.79
107.1	-164.55	-223.77	-235.68	-94.33	-.99	-.87	-.79	-.72	-.72
108.1	-151.77	-211.65	-239.83	-214.09	-1.07	-.77	-.69	-.66	-.65
108.9	-142.66	-203.36	-285.18	-1092.68	-2482.83	-2314.54	-2317.21	-2321.20	-2283.81
109.4	-135.96	-189.24	-352.26	-1150.16	-2017.14	-2271.68	-2316.48	-2322.84	-2285.59
110.1	-124.90	-133.94	-78.26	-41.81	-24.42	-12.79	-8.74	-6.67	-6.98
111.1	-116.96	-100.34	-56.16	-45.88	-36.57	-24.30	-17.58	-12.86	-13.78
112.1	-119.58	-90.66	-52.33	-46.14	-40.23	-30.26	-23.50	-17.84	-19.15
113.1	-16.16	-9.48	-9.18	-9.95	-9.82	-8.55	-7.33	-6.18	-6.34
115.1	-24.25	-17.87	-16.09	-15.43	-14.86	-13.89	-13.15	-12.47	-13.20
117.1	-24.10	-20.56	-19.37	-18.89	-18.48	-17.83	-17.38	-17.07	-17.84
118.1	-48.90	-43.79	-41.92	-41.13	-40.46	-39.41	-38.71	-38.36	-39.92
120.6	-47.12	-45.95	-44.17	-43.79	-43.46	-42.94	-42.63	-42.70	-44.17
125.1	-45.57	-45.42	-45.37	-45.35	-45.36	-45.42	-45.56	-46.11	-47.38
130.1	-44.87	-45.39	-45.65	-45.78	-45.92	-46.22	-46.54	-47.28	-48.41
135.1	-44.52	-45.26	-45.63	-45.81	-45.99	-46.37	-46.75	-47.54	-48.57
139.6	-44.38	-45.18	-45.57	-45.77	-45.97	-46.36	-46.76	-47.55	-48.34
142.1	-44.36	-45.17	-45.57	-45.76	-45.96	-46.36	-46.76	-47.55	-48.54

HEAT FLOW IN POSITIVE X-DIRECTION (W/M2)

Z-DIST \ R-DIST	69.0	70.0	71.0	71.5	72.0	73.0	75.0	76.0	77.5
.5	-110.82	-110.83	-110.85	-110.85	-110.86	-111.05	-111.43	-111.61	.00
5.5	-110.82	-110.83	-110.84	-110.85	-110.85	-111.05	-111.43	-111.62	.00
15.0	-110.74	-110.75	-110.77	-110.77	-110.78	-111.03	-111.51	-111.76	.00
25.0	-110.53	-110.55	-110.58	-110.59	-110.60	-110.97	-111.71	-112.08	.00
35.0	-110.12	-110.16	-110.19	-110.21	-110.23	-110.85	-112.08	-112.69	.00
45.0	-109.33	-109.38	-109.44	-109.48	-109.51	-110.57	-112.70	-113.76	.00
55.0	-107.75	-107.84	-107.95	-108.01	-108.07	-109.95	-113.73	-115.62	.00
65.0	-104.53	-104.69	-104.88	-104.99	-105.10	-108.53	-115.45	-118.91	.00
74.0	-98.45	-98.70	-99.03	-99.22	-99.42	-105.57	-118.00	-124.21	.00
81.5	-88.94	-89.32	-89.84	-90.15	-90.49	-100.63	-121.17	-131.42	.00
87.5	-75.58	-76.18	-76.99	-77.46	-77.98	-93.53	-124.86	-140.44	.00
92.5	-58.77	-59.93	-61.37	-62.14	-62.94	-85.95	-129.85	-150.89	.00
96.0	-40.39	-43.62	-47.59	-49.52	-51.24	-93.32	-144.33	-160.98	.00
98.0	-25.75	-31.31	-40.20	-45.77	-50.97	-141.82	-176.35	-167.25	.00
99.5	-7.99	-12.09	-25.63	-47.30	-92.54	-325.41	-253.19	-171.75	.00
100.3	-2935.92	-2871.59	-2634.77	-1920.80	-1449.14	-551.73	-314.31	-349.39	-228.92
100.7	-2935.32	-2903.43	-2998.59	-1686.08	-1006.91	-572.80	-329.44	-306.83	-227.51
101.5	-.84	-.94	-1.30	-465.83	-663.36	-526.25	-327.37	-265.73	-220.36
102.5	-.90	-1.01	-1.17	-224.70	-482.12	-438.98	-299.43	-237.28	-208.93
103.9	-.92	-1.00	-1.09	-141.19	-355.06	-341.55	-253.24	-197.53	-181.30
105.7	-.87	-.93	-1.01	-108.55	-290.63	-282.17	-218.95	-178.35	-167.58
107.1	-.77	-.84	-.96	-121.56	-290.53	-274.70	-207.43	-169.33	-159.67
108.1	-.66	-.73	-1.00	-246.53	-324.73	-281.15	-202.32	-164.71	-155.01
108.9	-2214.74	-2170.34	-2246.64	-1076.06	-416.31	-283.89	-197.35	-162.71	-152.19
109.4	-2215.67	-2139.30	-1890.03	-1170.79	-540.11	-270.85	-192.67	-162.14	-150.51
110.1	-10.08	-16.10	-33.89	-60.93	-117.49	-193.72	-183.53	-163.04	-148.20
111.1	-20.91	-30.39	-47.78	-61.24	-76.36	-145.19	-161.64	-173.09	-144.95
112.1	-27.80	-36.78	-48.93	-54.88	-59.43	-130.12	-197.65	-204.80	-136.94
113.1	-8.62	-10.32	-11.95	-11.98	-10.80	-13.99	-31.48	-84.78	-107.07
115.1	-15.25	-16.89	-18.98	-20.25	-21.77	-25.86	-39.65	-50.12	-69.51
117.1	-19.47	-20.69	-22.21	-23.11	-24.12	-26.54	-33.50	-40.43	-59.20
118.1	-42.91	-45.05	-47.63	-49.08	-50.66	-54.07	-60.75	-58.35	-62.95
120.6	-46.46	-47.93	-49.60	-50.47	-51.39	-53.26	-56.67	-58.28	-60.67
125.1	-48.85	-49.71	-50.63	-51.11	-51.60	-52.60	-54.61	-55.55	-56.89
130.1	-49.46	-50.03	-50.61	-50.90	-51.21	-51.81	-53.00	-53.56	-54.34
135.1	-49.43	-49.87	-50.30	-50.51	-50.73	-51.16	-51.97	-52.34	-52.86
139.6	-49.33	-49.72	-50.10	-50.28	-50.47	-50.83	-51.51	-51.92	-52.24
142.1	-49.32	-49.70	-50.07	-50.25	-50.44	-50.80	-51.46	-51.76	-52.17

HEAT FLOW IN POSITIVE X-DIRECTION (W/M2)

Z-DIST	R-DIST 79.0	80.0	82.0	87.0	92.0	97.0	102.0	107.0	108.0
.5	.00	.00	.00	.00	.00	.00	.00	.00	.00
5.5	.00	.00	.00	.00	.00	.00	.00	.00	.00
15.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
25.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
35.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
45.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
55.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
65.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
74.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
81.5	.00	.00	.00	.00	.00	.00	.00	.00	.00
87.5	.00	.00	.00	.00	.00	.00	.00	.00	.00
92.5	.00	.00	.00	.00	.00	.00	.00	.00	.00
96.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
98.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
99.5	.00	.00	.00	.00	.00	.00	.00	.00	.00
100.3	-176.07	-152.34	-120.14	-78.94	-57.00	-44.00	-35.70	-30.03	-29.07
100.7	-178.47	-155.14	-122.78	-80.85	-58.44	-45.13	-36.63	-30.82	-29.83
101.5	-179.27	-157.54	-125.91	-83.43	-60.45	-46.75	-37.98	-31.98	-30.96
102.5	-175.79	-156.81	-128.00	-86.09	-62.76	-48.71	-39.67	-33.46	-32.41
103.9	-162.97	-151.50	-128.52	-88.77	-65.48	-51.17	-41.88	-35.45	-34.36
105.7	-154.32	-144.71	-125.90	-90.08	-67.81	-53.69	-44.35	-37.79	-36.68
107.1	-147.80	-139.08	-122.25	-89.74	-68.80	-55.17	-45.99	-39.45	-38.33
108.1	-143.28	-134.87	-119.09	-89.03	-69.22	-56.04	-47.05	-40.57	-39.46
108.9	-139.88	-131.46	-116.32	-88.19	-69.33	-56.57	-47.78	-41.37	-40.25
109.4	-137.53	-129.04	-114.33	-87.54	-69.35	-56.89	-48.24	-41.89	-40.77
110.1	-133.78	-125.12	-111.14	-86.44	-69.28	-57.31	-48.89	-42.64	-41.53
111.1	-127.48	-118.79	-106.30	-84.66	-68.99	-57.72	-49.68	-43.61	-42.47
112.1	-118.25	-110.84	-100.90	-82.65	-68.52	-58.00	-50.38	-44.55	-43.36
113.1	-104.42	-101.25	-95.13	-80.47	-67.91	-58.16	-51.02	-45.50	-44.19
115.1	-78.68	-81.96	-83.52	-75.94	-66.46	-58.29	-52.16	-47.53	-45.70
117.1	-68.13	-72.64	-75.84	-71.87	-64.69	-57.92	-52.93	-51.37	-46.63
118.1	-67.83	-69.92	-72.68	-69.96	-63.79	-57.67	-53.19	-54.77	-68.39
120.6	-63.01	-64.31	-66.16	-65.54	-61.53	-56.88	-53.21	-52.17	-51.93
125.1	-58.09	-58.77	-59.79	-60.03	-57.92	-54.74	-51.35	-47.70	-46.60
130.1	-55.02	-55.41	-56.00	-56.28	-54.97	-52.59	-49.53	-45.81	-44.92
135.1	-53.31	-53.56	-53.94	-54.10	-53.09	-51.11	-48.39	-45.05	-44.33
139.6	-52.60	-52.80	-53.10	-53.20	-52.28	-50.45	-47.90	-44.80	-44.15
142.1	-52.52	-52.72	-53.01	-53.10	-52.19	-50.38	-47.85	-44.77	-44.13

HEAT FLOW IN POSITIVE Y-DIRECTION (W/M2)

Z-DIST	R-DIST .5	2.0	3.5	6.5	11.5	16.5	21.5	26.5
.0	.00	.00	.00	.00	.00	.00	.00	.00
1.0	.00	.00	.00	.00	.00	.00	.00	.00
10.0	.00	.00	.00	.00	.00	.00	.00	.00
20.0	.00	.00	.00	.00	.00	.00	.00	.00
30.0	.00	.00	.00	.00	.00	.00	.00	.00
40.0	.00	.00	.00	.00	.00	.00	.00	.00
50.0	.00	.00	.00	.00	.00	.00	.00	.00
60.0	.00	.00	.00	.00	.00	.00	.00	.00
70.0	.00	.00	.00	.00	.00	.00	.00	.00
78.0	.00	.00	.00	.00	.00	.00	.00	.00
85.0	.00	.00	.00	.00	.00	.00	.00	.00
90.0	.00	.00	.00	.00	.00	.00	.00	.00
95.0	.00	.00	.00	.00	.00	.00	.00	.00
97.0	.00	.00	.00	.00	.00	.00	.00	.00
99.0	.00	.00	.00	.00	.00	.00	.00	.00
100.0	.00	.00	-4.33	-6.76	-10.94	-15.63	-20.95	-27.36
100.5	.00	.00	-4.32	-6.73	-10.95	-15.56	-20.83	-27.18
101.0	.00	.00	-4.31	-6.71	-10.91	-15.48	-20.71	-26.98
102.0	.00	.00	-4.27	-6.66	-10.80	-15.31	-20.43	-26.53
103.0	.00	.00	-4.24	-6.60	-10.69	-15.11	-20.11	-26.02
104.8	.00	.00	-4.17	-6.49	-10.45	-14.69	-19.44	-24.97
106.6	.00	.00	-4.09	-6.36	-10.17	-14.21	-18.68	-23.77
107.6	.00	.00	-4.04	-6.28	-10.00	-13.92	-18.21	-23.05
108.6	.00	.00	-4.00	-6.21	-9.83	-13.61	-17.73	-22.32
109.1	.00	.00	-3.98	-6.18	-9.74	-13.45	-17.48	-21.94
109.6	.00	.00	-3.96	-6.14	-9.65	-13.28	-17.23	-21.56
110.6	.00	.00	-3.92	-6.08	-9.46	-12.95	-16.71	-20.79
111.6	.00	.00	-3.90	-6.02	-9.27	-12.61	-16.16	-20.01
112.6	.00	.00	-3.89	-5.98	-9.07	-12.25	-15.64	-19.22
113.6	.00	.00	-3.91	-5.95	-8.87	-11.89	-15.10	-18.44
116.6	.00	.00	-4.20	-5.97	-8.26	-10.76	-13.42	-16.10
117.6	-9.32	-12.47	-4.68	-6.03	-8.03	-10.37	-12.86	-15.34
118.6	-7.30	-8.68	-6.78	-6.11	-7.80	-9.97	-12.30	-14.60
122.6	-3.60	-4.40	-4.73	-5.27	-6.66	-8.33	-10.08	-11.73
127.6	-2.05	-2.57	-3.00	-3.79	-4.98	-6.20	-7.39	-8.46
132.6	-1.22	-1.55	-1.85	-2.43	-3.28	-4.09	-4.84	-5.48
137.6	-.59	-.74	-.90	-1.19	-1.63	-2.03	-2.39	-2.69
141.6	-.12	-.15	-.18	-.24	-.33	-.41	-.48	-.54
142.6	.00	.00	.00	.00	.00	.00	.00	.00

HEAT FLOW IN POSITIVE Y-DIRECTION (W/M2)

Z-DIST	R-DIST 31.5	36.5	41.5	46.5	50.3	52.0	53.2	54.7	56.0
.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
1.0	.00	.00	.00	.00	.00	.00	.00	.00	.03
10.0	.00	.00	.00	.00	.00	.00	.00	.00	.27
20.0	.00	.00	.00	.00	.00	.00	.00	.00	.48
30.0	.00	.00	.00	.00	.00	.00	.00	.00	.45
40.0	.00	.00	.00	.00	.00	.00	.00	.00	-.33
50.0	.00	.00	.00	.00	.00	.00	.00	.00	-3.34
60.0	.00	.00	.00	.00	.00	.00	.00	.00	-12.35
70.0	.00	.00	.00	.00	.00	.00	.00	.00	-36.96
78.0	.00	.00	.00	.00	.00	.00	.00	.00	-85.04
85.0	.00	.00	.00	.00	.00	.00	.00	.00	-170.96
90.0	.00	.00	.00	.00	.00	.00	.00	.00	-280.02
95.0	.00	.00	.00	.00	.00	.00	.00	.00	-447.80
97.0	.00	.00	.00	.00	.00	.00	.00	.00	-521.68
99.0	.00	.00	.00	.00	.00	.00	.00	.00	-558.96
100.0	-35.55	-46.71	-63.20	-90.43	-129.72	-159.08	-185.88	-242.05	-525.30
100.5	-35.25	-46.15	-62.09	-87.84	-123.23	-148.13	-162.05	-175.49	-525.30
101.0	-34.91	-45.55	-60.89	-85.03	-116.26	-135.70	-140.10	-132.37	-492.44
102.0	-34.16	-44.21	-58.22	-78.89	-101.49	-110.46	-104.58	-85.48	-386.86
103.0	-33.32	-42.71	-55.28	-72.38	-87.08	-88.70	-78.64	-58.90	-287.60
104.8	-31.59	-39.68	-49.54	-60.40	-64.15	-59.61	-48.89	-33.29	-159.93
106.6	-29.66	-36.43	-43.66	-49.18	-45.88	-39.37	-30.11	-18.36	-78.52
107.6	-28.54	-34.59	-40.50	-43.50	-37.32	-30.34	-22.03	-12.09	-42.81
108.6	-27.40	-32.76	-37.44	-38.27	-29.70	-22.37	-15.01	-6.72	-11.86
109.1	-26.82	-31.86	-35.97	-35.83	-26.17	-18.58	-11.68	-4.24	1.49
109.6	-26.25	-30.96	-34.55	-33.53	-22.83	-14.87	-8.43	-1.85	12.74
110.6	-25.09	-29.21	-31.84	-29.32	-16.64	-7.36	-1.91	2.96	27.47
111.6	-23.95	-27.52	-29.33	-25.69	-11.23	1.42	5.16	9.45	35.03
112.6	-22.82	-25.89	-27.04	-22.68	-7.16	14.24	12.43	21.85	39.12
113.6	-21.71	-24.34	-24.98	-20.33	-6.33	5.75	8.07	15.25	19.29
116.6	-18.54	-20.18	-20.04	-16.62	-11.46	-10.22	-2.85	1.62	3.53
117.6	-17.54	-18.93	-18.66	-15.66	-12.63	-18.38	-7.61	-.99	1.18
118.6	-16.58	-17.76	-17.39	-14.75	-12.17	-11.39	-7.75	-3.63	-1.74
122.6	-13.04	-13.67	-13.20	-11.41	-9.33	-8.13	-7.15	-6.00	-5.32
127.6	-9.24	-9.53	-9.17	-8.10	-6.96	-6.41	-6.03	-5.63	-5.38
132.6	-5.92	-6.06	-5.83	-5.26	-4.69	-4.44	-4.27	-4.09	-3.98
137.6	-2.89	-2.95	-2.85	-2.60	-2.36	-2.26	-2.19	-2.12	-2.07
141.6	-.58	-.59	-.57	-.52	-.47	-.45	-.44	-.42	-.41
142.6	.00	.00	.00	.00	.00	.00	.00	.00	.00

HEAT FLOW IN POSITIVE Y-DIRECTION (W/M2)

Z-DIST \ R-DIST	57.5	59.0	59.7	60.2	61.0	62.0	63.5	65.7	68.0
.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
1.0	.03	.03	.00	.00	.00	.01	.01	.01	.01
10.0	.28	.29	.02	.03	.04	.05	.06	.08	.10
20.0	.50	.53	.04	.06	.07	.10	.13	.18	.23
30.0	.48	.54	.05	.07	.11	.15	.22	.32	.41
40.0	-.31	-.22	.01	.05	.11	.19	.32	.51	.70
50.0	-3.39	-3.25	-.19	-.11	.01	.16	.41	.78	1.14
60.0	-12.64	-12.45	-.80	-.65	-.43	-.12	.36	1.09	1.83
70.0	-37.93	-37.69	-2.51	-2.22	-1.77	-1.15	-.18	1.33	2.87
78.0	-87.38	-87.14	-5.89	-5.37	-4.56	-3.43	-1.66	1.14	4.01
85.0	-175.80	-175.69	-11.98	-11.08	-9.70	-7.75	-4.69	.22	5.29
90.0	-288.32	-288.90	-19.81	-18.52	-16.50	-13.59	-8.93	-1.26	6.58
95.0	-465.26	-473.55	-32.88	-31.39	-28.84	-24.49	-16.84	-3.68	9.54
97.0	-557.44	-604.28	-43.24	-42.75	-40.32	-34.07	-22.65	-4.70	12.89
99.0	-634.84	-855.17	-70.98	-72.16	-63.86	-49.12	-29.20	-5.46	17.24
100.0	-601.26	-1146.97	-185.55	-127.17	-81.13	-54.43	-30.42	-5.55	18.12
100.5	-525.72	-574.90	147.60	448.61	59.08	17.62	24.83	35.85	48.67
101.0	-446.22	-298.26	704.15	1533.28	.50	.17	-.01	-.08	-.14
102.0	-312.59	-122.30	246.63	382.92	.15	.07	-.03	-.08	-.13
103.0	-217.65	-65.84	-260.57	-220.87	-.03	-.03	-.06	-.08	-.10
104.8	-115.48	-33.99	-919.02	-903.84	-.22	-.18	-.14	-.08	-.03
106.6	-53.29	-17.51	-1385.02	-1384.38	-.36	-.30	-.21	-.09	.04
107.6	-23.64	-5.45	-1582.24	-1642.12	-.48	-.39	-.24	-.09	.07
108.6	6.35	22.91	-1551.83	-2137.56	-.78	-.47	-.25	-.09	.08
109.1	21.59	63.96	-689.93	-747.41	-48.87	36.85	39.05	31.64	23.63
109.6	34.87	145.47	108.71	68.57	36.28	17.20	.92	-14.17	-30.89
110.6	39.38	89.78	35.77	33.74	24.62	13.12	-.14	-14.07	-29.35
111.6	31.09	45.62	15.22	15.09	12.35	6.39	-2.50	-13.69	-25.77
112.6	16.57	7.24	2.81	3.23	2.37	-.39	-5.34	-13.18	-21.45
113.6	13.22	6.94	4.34	2.97	1.08	-1.59	-5.94	-13.02	-20.44
116.6	3.64	1.63	.40	-.47	-1.83	-3.80	-6.96	-12.14	-17.36
117.6	1.88	.44	-.55	-1.29	-2.47	-4.24	-7.11	-11.83	-16.53
118.6	-.67	-1.43	-2.10	-2.63	-3.53	-4.94	-7.29	-11.21	-15.04
122.6	-4.81	-4.93	-5.13	-5.30	-5.62	-6.17	-7.15	-8.85	-10.46
127.6	-5.17	-5.16	-5.20	-5.25	-5.33	-5.49	-5.78	-6.31	-6.77
132.6	-3.88	-3.84	-3.83	-3.84	-3.85	-3.88	-3.94	-4.05	-4.13
137.6	-2.02	-1.99	-1.98	-1.98	-1.98	-1.97	-1.98	-1.98	-1.97
141.6	-.40	-.40	-.40	-.40	-.39	-.39	-.39	-.39	-.39
142.6	.00	.00	.00	.00	.00	.00	.00	.00	.00

HEAT FLOW IN POSITIVE Y-DIRECTION (W/M2)

Z-DIST	R-DIST 69.5	70.5	71.2	71.7	72.5	74.0	75.5	76.7	78.2
.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
1.0	.01	.01	.01	.01	.19	.19	.19	.00	.00
10.0	.12	.12	.13	.13	1.91	1.92	1.90	.00	.00
20.0	.26	.28	.29	.30	4.35	4.36	4.33	.00	.00
30.0	.47	.51	.54	.56	8.06	8.08	8.02	.00	.00
40.0	.82	.89	.95	.99	14.19	14.23	14.14	.00	.00
50.0	1.38	1.53	1.64	1.72	24.77	24.86	24.71	.00	.00
60.0	2.31	2.63	2.86	3.01	43.58	43.79	43.53	.00	.00
70.0	3.88	4.55	5.03	5.35	77.93	78.42	78.00	.00	.00
78.0	5.92	7.17	8.09	8.69	127.18	128.17	127.53	.00	.00
85.0	8.63	10.82	12.43	13.48	198.31	200.08	199.16	.00	.00
90.0	11.63	14.88	17.22	18.75	276.17	278.44	276.94	.00	.00
95.0	17.41	22.08	25.03	26.83	391.37	388.21	382.00	.00	.00
97.0	23.87	30.02	32.79	33.73	475.63	439.26	415.25	.00	.00
99.0	35.00	47.81	55.10	54.59	657.42	473.82	396.98	.00	.00
100.0	39.11	61.36	98.46	145.10	890.42	437.79	315.55	156.57	138.24
100.5	50.47	-13.22	-558.96	-324.24	441.73	378.52	333.16	116.43	120.64
101.0	-.32	-.65	-1865.99	-1052.49	224.57	317.66	321.80	89.99	104.29
102.0	-.22	-.29	-860.16	-739.60	87.31	218.21	260.11	59.74	76.89
103.0	-.12	-.12	-335.81	-305.99	44.03	148.43	197.91	40.83	54.80
104.8	.02	.06	315.26	324.33	19.48	68.96	97.54	21.36	32.80
106.6	.15	.21	852.66	848.01	4.07	12.09	24.42	8.43	16.90
107.6	.22	.33	1180.60	1118.11	-11.82	-21.50	-13.68	1.99	8.98
108.6	.30	.61	1760.65	1207.64	-55.45	-60.92	-51.18	-4.48	1.17
109.1	20.83	82.91	617.84	523.11	-121.60	-82.47	-68.44	-7.97	-2.93
109.6	-51.61	-77.68	-124.42	-183.63	-256.30	-102.04	-83.76	-11.86	-7.25
110.6	-45.60	-59.90	-70.32	-70.47	-180.08	-107.15	-104.31	-21.75	-16.87
111.6	-36.10	-42.49	-43.35	-40.17	-111.33	-88.86	-112.88	-40.52	-28.51
112.6	-27.12	-30.34	-31.40	-31.03	-40.71	-55.16	-105.84	-85.77	-49.97
113.6	-25.42	-28.71	-31.34	-33.41	-37.52	-46.43	-52.55	-70.91	-42.74
116.6	-20.52	-22.43	-23.64	-24.35	-25.24	-25.74	-21.13	-32.13	-24.40
117.6	-19.30	-20.90	-21.83	-22.33	-22.81	-22.26	-14.19	-19.61	-18.44
118.6	-17.16	-18.32	-18.91	-19.19	-19.41	-18.92	-16.59	-16.56	-15.19
122.6	-11.26	-11.65	-11.82	-11.89	-11.93	-11.71	-10.95	-10.20	-8.94
127.6	-6.96	-7.02	-7.02	-7.00	-6.94	-6.70	-6.22	-5.72	-4.95
132.6	-4.12	-4.09	-4.04	-4.00	-3.93	-3.73	-3.42	-3.12	-2.68
137.6	-1.94	-1.90	-1.87	-1.85	-1.80	-1.69	-1.54	-1.40	-1.19
141.6	-.38	-.37	-.37	-.36	-.35	-.33	-.30	-.27	-.23
142.6	.00	.00	.00	.00	.00	.00	.00	.00	.00

HEAT FLOW IN POSITIVE Y-DIRECTION (W/M2)

Z-DIST	R-DIST 79.5	81.0	84.5	89.5	94.5	99.5	104.5	107.5	109.5
.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
1.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
10.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
20.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
30.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
40.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
50.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
60.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
70.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
78.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
85.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
90.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
95.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
97.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
99.0	.00	.00	.00	.00	.00	.00	.00	.00	.00
100.0	126.48	114.28	91.84	70.76	55.55	43.80	34.27	29.46	.00
100.5	114.64	106.25	87.73	68.58	54.25	42.98	33.71	28.98	.00
101.0	102.97	98.16	83.53	66.34	52.92	42.13	33.12	28.49	.00
102.0	81.24	82.34	75.04	61.74	50.18	40.37	31.92	27.47	.00
103.0	62.25	67.94	66.65	57.08	47.37	38.57	30.68	26.42	.00
104.8	41.60	47.25	52.34	48.69	42.22	35.22	28.36	24.46	.00
106.6	24.29	30.32	39.45	40.68	37.13	31.86	26.00	22.45	.00
107.6	15.58	21.90	32.95	36.49	34.41	30.03	24.70	21.33	.00
108.6	7.18	14.01	26.95	32.53	31.78	28.23	23.40	20.22	.00
109.1	2.98	10.24	24.14	30.65	30.51	27.35	22.76	19.66	.00
109.6	-1.27	6.56	21.46	28.83	29.26	26.49	22.13	19.10	.00
110.6	-9.93	-.44	16.52	25.40	26.86	24.80	20.88	17.98	.00
111.6	-18.62	-6.69	12.19	22.26	24.61	23.20	19.67	16.65	.00
112.6	-26.03	-11.66	8.54	19.44	22.50	21.67	18.50	15.66	.00
113.6	-29.20	-14.72	5.60	16.92	20.55	20.24	17.40	14.35	.00
116.6	-19.37	-12.38	1.06	11.23	15.65	16.56	14.62	8.86	.00
117.6	-14.86	-10.78	.27	9.80	14.31	15.57	14.31	4.12	39.64
118.6	-12.78	-9.41	-.28	8.56	13.08	14.67	14.62	17.74	30.90
122.6	-7.57	-5.72	-.77	5.35	9.36	11.73	13.80	16.78	19.15
127.6	-4.18	-3.18	-.53	3.23	6.18	8.34	10.15	11.29	11.96
132.6	-2.25	-1.69	-.25	1.93	3.80	5.28	6.43	6.88	7.11
137.6	-.99	-.74	-.09	.92	1.82	2.55	3.09	3.26	3.34
141.6	-.19	-.14	-.01	.18	.36	.51	.62	.65	.66
142.6	.00	.00	.00	.00	.00	.00	.00	.00	.00

APPENDIX B:

TOTAL WINDOW U-VALUE SAMPLE CALCULATION

Appendix B: Total Window U-Value Sample Calculation

Figure B1 displays a typical window of glazing width, W, and height, H. For the calculation of the total window U-value the window is subdivided into four components: the centre glazing, edge glazing, sill, and frame. For all cases, the edge glazing was assumed to be 100 mm of the perimeter glazing, as shown in Figure B1 (i.e. $D_2 = 0.100$).

The area of each component can be calculated using the following equations:

$$A_1 = 2\ D_1\ (W - 2\ D_2)$$
$$A_2 = 2\ D_2\ (W + H - 2\ D_2)$$
$$A_3 = 2\ D_3\ (W + H)$$
$$A_4 = 2\ D_4\ (W + H + 2\ D_4)$$

where A_1 is the total projected centre glazing area,
A_2 is the total projected edge glazing area,
A_3 is the total sill area,
A_4 is the total projected frame area,
D is the depth of each surface as shown in Figure B1.

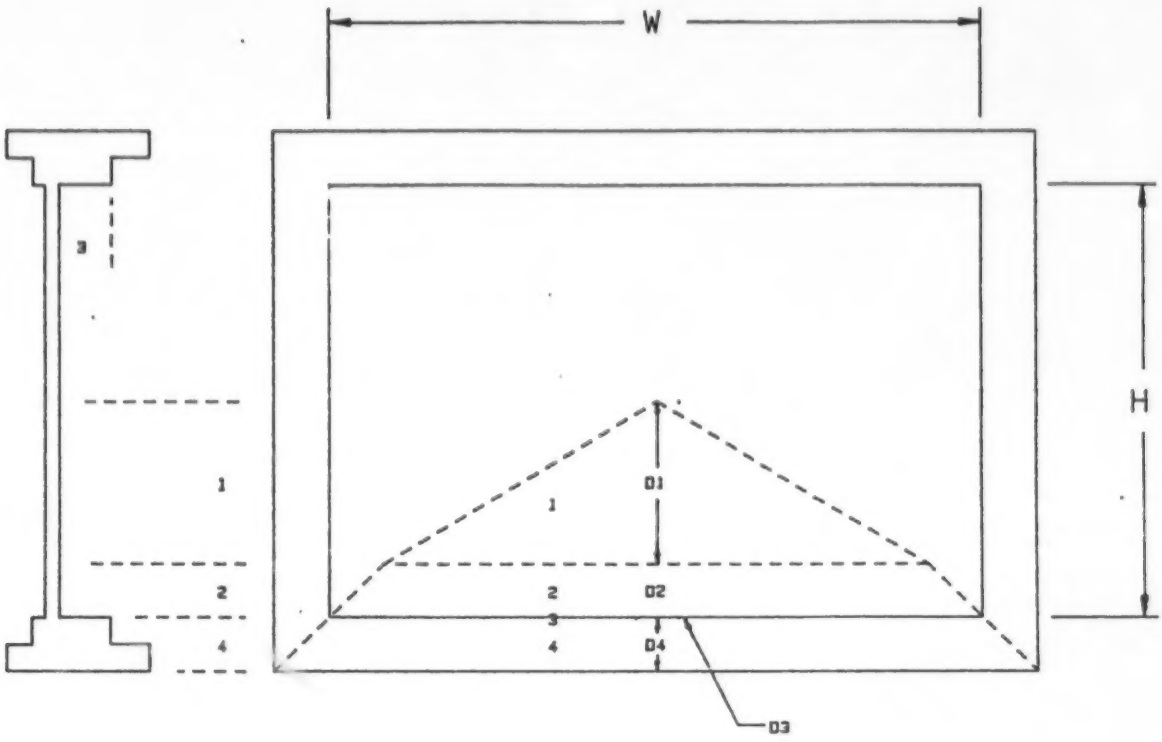
Choosing the wood frame and fiberglass spacer as an example (program output presented in Appendix A), and assuming a rectangular glazing of 1.0 m x 2.0 m, the total window U-value is calculated as follows:

$$D_4 = 0.0425 \text{ m}$$
$$D_3 = 0.0320 \text{ m}$$
$$D_2 = 0.1000 \text{ m}$$
$$D_1 = (H/2 - D_2) = 0.4 \text{ m}.$$

Therefore,

$$A_1 = 1.44$$
$$A_2 = 0.5600$$
$$A_3 = 0.1920$$
$$A_4 = 0.2622\ .$$

FIGURE B1. WINDOW COMPONENTS



1 - Centre Glazing
2 - Edge Glazing
3 - Sill
4 - Frame
D - Depth of Surface

And, from Appendix A,

$$q_2 = 11.3548 \text{ W}$$
$$q_3 = 1.7877 \text{ W}$$
$$q_4 = 0.5786 + 0.2710 + 0.7518 = 1.6014 \text{ W}.$$

Therefore, for the total window,

$$Q_2 = q_2 \cdot A_2 / D_2 = 63.59 \text{ W}$$
$$Q_3 = 10.73 \text{ W}$$
$$Q_4 = 9.88 \text{ W}.$$

From a one dimensional analysis of the centre glazing,

$$Q_1 = A_1 (T)/ R_t$$
$$= 1.44 (39) / (0.035+0.004+(0.0125/0.071)+0.004+0.132)$$
$$= 159.97 \text{ W}.$$

Therefore, the total heat flow and projected window area are,

$$Q_t = Q_1 + Q_2 + Q_3 + Q_4$$
$$= 244.17 \text{ W}$$

$$A_p = A_1 + A_2 + A_4$$
$$= 2.2622 \text{ m}^2.$$

And the total U-value is,

$$U = Q_t / A_p \ T$$
$$= 244.17 / (2.2622)(39)$$
$$= 2.77 \ (\text{W/m}^2\text{/K}).$$

Therefore, the wood frame with the fiberglass spacer has an overall U-value of 2.77 $\text{W/m}^2\text{/K}$.